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Shyamal K. Majumdar, Ph.D.
Editor
Department of Biology
Lafayette College
Easton, PA 18042-1778

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Shyamal K. Majumdar, Editor
Department of Biology
Lafayette College, Easton, PA 18042
Phone: (610) 330-5464
FAX: (610) 330-5705
E-Mail: Majumdas@lafayette.edu

EDITORIAL COMMITTEE MEMBERS

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BIOLOGY AND DIET OF THE NORTHERN MADTOM (*NOTURUS STIGMOSUS*) AND STONECAT (*NOTURUS FLAVUS*) IN FRENCH CREEK, PENNSYLVANIA[1]

CALEB J. TZILKOWSKI and JAY R. STAUFFER, JR.

School of Forest Resources
The Pennsylvania State University
University Park, Pennsylvania 16802, USA

ABSTRACT

Age, oocyte condition, body size at reproductive maturity, and diet of the only Pennsylvania northern madtom *Noturus stigmosus* Taylor population were compared to the closely related, syntopic stonecat *Noturus flavus* Rafinesque. All mature stonecat females were larger (101.8–140.7 mm, SL) than mature northern madtom females (60.9–85.2) but oocytes of both species were similar in appearance and diameter (stonecat $\bar{x}$ = 1.98 mm, CV = 3.98; northern madtom $\bar{x}$ = 1.83, CV = 4.69) to those of other ictalurids. Stonecat clutch sizes were much larger ($\bar{x}$ = 261, CV = 5.0), than those of the northern madtom ($\bar{x}$ = 98, CV = 5.8), but relative fecundity was greater for the northern madtom ($\bar{x}$ = 20.2, CV = 5.5) than the stonecat ($\bar{x}$ = 13.5, CV = 7.5). Both species were primarily generalist feeders but the most preferred prey of each species was less preferred by the other; additionally, small stonecats had a diet more similar to similarly-sized northern madtoms than they did with larger stonecats. Stonecats averaged nearly 40% greater SL than northern madtoms; consequently, they had greater absolute fecundity and shifted their diet to include larger prey items. This study provided; 1) important, previously unavailable information regarding northern madtom biology and 2) evidence of subtle differences among syntopic madtom species that may minimize resource overlap.
[J PA Acad Sci 78 (1): 3-11, 2004]

INTRODUCTION

Madtom catfishes (genus *Noturus*) represent the most speciose (25 described and valid species) and least understood genus of ictalurid catfish (Burr and Stoeckel, 1999). Half of madtom species are listed as endangered or threatened at the state or federal level (U. S. Fish and Wildlife Service, 1998); consequently, imperiled madtoms are poorly understood, in part, because endangered species regulations typically prohibit collection of specimens for study. Life history information is lacking for the northern madtom *Noturus stigmosus* Taylor, which is naturally rare throughout its disjunct range and documented at only four sites within one stream in Pennsylvania (French Creek, Gutowski and Raesly 1993). Although not federally endangered, the northern madtom is protected by imperiled designation in several states (Michigan: Miller, 1972; Kentucky, Tennessee, Mississippi, and West Virginia: Johnson, 1987; Pennsylvania, Pennsylvania Fish and Boat Commission, http://sites.state.pa.us/PA–Exec/Fish–Boat/endangered/species–list.pdf). The lack of northern madtom life history information is confirmed by its near absence from Burr and Stoeckel's (1999) thorough review of madtom natural history. Furthermore, the limited northern madtom fecundity data available are variable and have been derived from small samples (n = 3 nests, MacInnis, 1998; n = 6 females, Burr and Stoeckel, 1999). Understanding the diet and reproductive biology of Pennsylvania's small, isolated, and potentially unique northern madtom population is important for protecting it from extirpation.

Few studies have investigated potential interspecific competition among madtoms (Wildhaber, et al., 1999); however, recognizing life history similarities among syntopically occurring fishes are essential for the conservation of rare species such as the northern madtom. The northern madtom and stonecat *Noturus flavus* Rafinesque have overlapping distributions and share similar habitat requirements. Both species inhabit riffles of warmwater streams and rivers with substrates of sand, sandy mud, gravel, or small pebbles (Taylor, 1969; Trautman, 1981; Cooper, 1983) and have also been found to inhabit lake shallows (Gilbert, 1953; MacInnis, 1998). The stonecat (the sole member of the subgenus *Noturus*) is the most common madtom in west-

[1]Submitted for publication 10 October 2003; accepted 27 February 2004.

ern Pennsylvania (Cooper, 1983) and the largest *Noturus* species (300 mm standard length (SL) in Lake Erie, Trautman, 1981; 180 mm SL in streams, Trautman, 1981; Walsh and Burr, 1985). The northern madtom is much smaller (130 mm maximum, Trautman, 1981) and belongs to the *Rabida* subgenus.

All madtoms spawn during spring and summer, although their start (Pfingsten and Edds, 1994) and duration depend on the species and locale. MacInnis (1998) observed northern madtoms in Lake St. Clair, Ontario guarding nests on 17 July and found a gravid female on 13 August 1996, suggesting a reproductive season of at least one month. The stonecat may have a longer reproductive season as suggested by maximum ovarian mass and peak spawning conditions observed by Walsh and Burr (1985) from 4 June–28 July. The stonecat and northern madtom are cavity nesters (Mayden and Burr, 1981) and usually spawn in or under natural substrata (e.g., stones, crayfish burrows, logs) or unnatural cavities (e.g., cans, bottles, boards; Taylor, 1969; Burr and Stoeckel, 1999).

The northern madtom and stonecat occur syntopically in French Creek and have similar habitats and spawning times, therefore, they may use the same resources. Objectives of this study were to; 1) document northern madtom age structure, fecundity, and diet in French Creek and 2) compare these life history attributes to those of a syntopic and more abundant madtom, the stonecat.

MATERIALS AND METHODS

We collected northern madtoms (n = 29) and stonecats (n = 87) from 1200–1400 hours on June 15, 1999 by seining and backpack electrofishing all accessible habitats in a 200 m reach (44–64 m wide) of French Creek near the village of Venango, PA (Latitude/Longitude: 40°46'17"/80°06'30").

French Creek is a fourth-order Allegheny River tributary that drains approximately 3,000 km^2 of southwestern New York and northwestern Pennsylvania. French Creek underwent a stream reversal event during glaciation that changed its course from the Great Lakes to the Ohio River drainage; consequently, it harbors an unusually high diversity of aquatic fauna, including several Pennsylvania-threatened or -endangered fish and mussel species. Although not quantified, most madtoms were collected from one large riffle downstream of bridge pilings. Fishes were fixed in 10 percent formalin then transferred to 50 percent isopropyl alcohol for permanent storage.

Nine D-frame kicknet samples (20 seconds, 250 μm mesh) were taken from the 200 m reach within one hour of the fish collections to characterize the available madtom food base. Kick samples are effective in pools, riffles, and runs, and typically collect 95 percent of the macroinvertebrate taxa present in a stream (Frost et al., 1970). Because madtoms were collected primarily from riffles, six kick samples were taken from riffles and batched with three from pool habitats. Macroinvertebrate collections were fixed in a solution of five percent formalin/20 percent isopropyl alcohol and transferred to 70 percent isopropyl alcohol for permanent storage.

There were 29 northern madtoms in the collection; therefore, 29 stonecats were randomly selected from the 87 collected to provide equal sample sizes for comparison. After removal of gonads and digestive tracts (esophagus rearward), individuals were measured to 0.01 mm SL, blotted dry, and weighed to 0.0001 g (Adjusted Body Weight, ABW = body weight without digestive tract and gonads). Northern madtoms were collected as state agency vouchers; consequently, we could not further damage specimens for otolith removal and were limited to removing pectoral spines from the right side to determine fish age. Pectoral spines were cleaned of all flesh and skin, and then mounted in casting resin. After drying, spine cross-sections were cut at the distal end of the basal groove using a rotary tool and diamond saw blade attachment (two blades, separated by a 1.0 mm-thick washer). Spine sections were polished to 0.5-0.8 mm using wetted 440-grit wet/dry sandpaper and examined under a compound microscope. Two readers determined fish age by counting annual rings on pectoral fin spine sections following methods of Ashley and Garling (1980).

Gonads were blotted dry and weighed to 0.0001 g. These weights were used to calculate the gonadosomatic index (GSI = [gonad weight (g) / ABW (g)] x 1000). Ovaries were dissected individually and oocytes were counted and classified using ovum development criteria developed by Heins and Rabito (1986) and Heins and Baker (1988), and summarized by Heins and Baker (1993 a, b). The ovum development classification was intended for North American darters (Percidae) and minnows (Cyprinidae), but is broadly applicable to other fishes that exhibit group synchronous ovum development (Wallace and Selman, 1981). For this study, clutches were defined as large, relatively synchronous oocytes recruited from a pool of smaller, heterogeneous, vitellogenic oocytes (Wallace and Selman, 1981; Heins and Rabito, 1986). Females were divided into groups according to the ordered classification reported by Baker and Heins (1994). Premature (PM) females contained small, white to cream yellow, translucent to opaque, maturing oocytes whereas mature (MA) females contained clutches of enlarged, unovulated, opaque yellow to yellow-orange polygonal oocytes (mature oocytes) with vitelline membranes not separated from the yolk mass. Ripening (MR) females had unovulated, distinctly yellow orange or orange, translucent to transparent, relatively spherical oocytes with the vitelline membrane slightly to moderately elevated.

Digital images were made of 10 randomly selected oocytes from each female that contained maturing oocytes using a scanner. Oocyte images were measured using the trace function of the computer program SigmaScan Pro (v. 2.0, Jandel Scientific, 1995). A pie shape (16 equally spaced radii) drawn on a transparency sheet provided a center location for each oocyte. After digitizing each position (i.e., x and y coordinates) where the oocyte edge and radii intersected, we recorded the positions to a spreadsheet and calculated average egg diameters. After oocytes were measured, entire ovaries were dried at 40.6 C for 24 h then weighed to 0.0001 g.

Stomachs were flushed of their contents and food items from both the kick sample and stomach contents were identified to the lowest possible taxonomic level (usually genus) and counted. Diet selectivity and overlap of the madtom species were determined using Strauss' (Strauss, 1979) and Schoener's (Schoener, 1971) indices. Strauss' index (L) is a selectivity index, calculated as $L = r_i - p_i$ where r_i is the relative abundance of prey type i in the diet and p_i is the relative abundance of prey type i in the environment. Strauss' index values range from +1 (complete preference) to −1 (perfect avoidance) for prey items. Schoener's index (C_{xy}) measures diet overlap between species and ranges from 0 to 1, calculated as $C_{xy} = 1 - 0.5\ (\Sigma|p_{xi} - p_{yi}|)$ where p_{xi} is the proportion of food type i used by species x and p_{yi} is the proportion of food type i used by species y. Diet overlap increases as Schoener's index values approach one from zero.

RESULTS

Three male (68.5–74.4 mm, $\bar{x}$ = 70.9, CV = 22.2) and 26 female (59.2–85.2 mm, $\bar{x}$ = 68.4, CV = 10.9) northern madtoms were collected whereas the subsample of stonecat individuals contained five males (101.3–132.4 mm, $\bar{x}$ = 120.0, CV = 11.0) and 24 females (71.2–151.6 mm, $\bar{x}$ = 103.6, CV = 5.5).

Age estimates

The standard method for determining age of larger catfish species (i.e. counting annual rings on the cross sections of pectoral spines) was often inconclusive for these madtoms because annual rings were not always discernable on the small spines. Among female northern madtoms (n = 8) and stonecats (n = 7) for which ages were determined, the youngest and oldest individuals of both species were two and four years old respectively. Although age could not be determined for any northern madtom males, one stonecat male (132.4 mm) was 4 years old.

Length-weight relationships

Standard length (SL) and adjusted body weight (ABW) of age 2 females overlapped between the species, but stonecats had greater average lengths and weights for all age groups. There were few northern madtom and stonecat males in the samples (n = 3 and 5 respectively); therefore, only females were used for calculation of weight-length relationships. The relationship between stonecat weight and length was Log ABW = − 4.78 + 3.00 SL (r = 0.99, n = 24) whereas the same relationship for northern madtoms was Log ABW = −4.89 + 3.03 Log SL (r = 0.93, n = 26).

Reproductive traits:

Stonecat and northern madtom oocytes were similar in appearance to those of other catfishes. Ovaries contained either only premature (PM), white oocytes, or a mixture of premature oocytes interspersed among maturing, larger, yellow-cream colored oocytes that were polygonal (MA) or spherical (MR). Although nearly twice the number (73 percent) of northern madtom females contained maturing oocytes as compared to stonecats (38 percent), all females of both species contained at least premature oocytes. One northern madtom female (76.5 mm) and one stonecat female (105.2 mm) contained MR oocytes.

Both species exhibited size overlap of females that contained only premature oocytes with those that contained mature oocytes, but average SL and ABW were greater for individuals that contained maturing oocytes than those with only premature oocytes (Figure 1). The smallest stonecat that contained mature oocytes was considerably larger (101.77 mm) than age 2 individuals (71.2 and 71.5 mm) which suggests that in French Creek, stonecats spawn later in the season during their second year or are not mature until age 3.

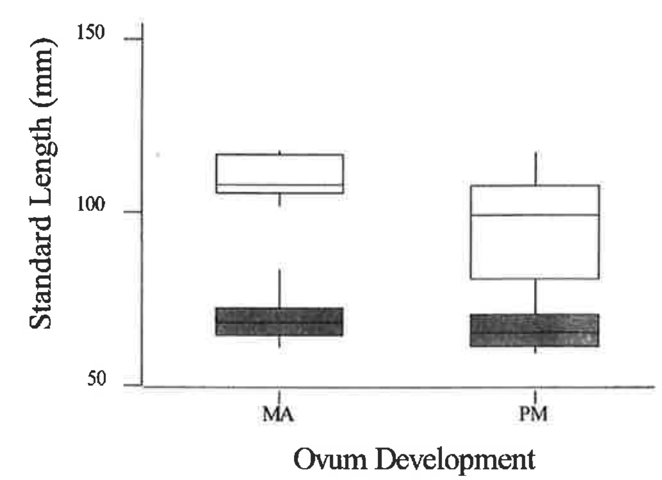

FIGURE 1. Standard length (mean, range, and interquartile range) of stonecat (open boxes) and northern madtom (shaded boxes) females that contained maturing (MA) or premature (PM) oocytes.

TABLE 1 Standard length (SL), adjusted body weight (ABW), and gonadosomatic index (GSI) values for northern madtoms and stonecats containing only premature (PM) or maturing oocytes (≥ MA). Sample sizes are given parenthetically next to ovum condition.

Species	SL (mm)		ABW (g)		GSI	
	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range
Northern madtom						
PM (7)	65.6	59.2–71.5	3.81	2.51–4.92	5.8	0.8–9.4
≥ MA (19)	69.4	60.9–85.2	5.03	3.29–8.54	21.9	5.9–46.0
Stonecat						
PM (14)	94.2	71.2–117.2	12.21	4.73–23.48	0.7	0.4–1.8
≥ MA (9)	112.8	101.8–140.7	19.79	13.75–34.17	24.6	2.9–51.1

Mature female northern madtoms in French Creek were 60.9–85.2 mm. No age 1 northern madtoms were collected; therefore, we could not determine if females were mature at age 1, but most (69 percent) females in the age 2 size class (63-68 mm, $n = 13$) contained maturing oocytes. Gonadosomatic index (GSI) values of mature females were considerably higher than premature females in both species and maximum GSI of mature individuals between the species were similar (Table 1). Although not correlated with body size (SL or ABW) for either species, stonecat oocyte diameters were slightly larger and more variable ($\bar{x} = 1.98$ mm, SD = 0.51) than those of the northern madtom ($\bar{x} = 1.83$, SD = 0.39).

Stonecat clutches were much larger (185–326, $\bar{x} = 261$, CV = 5.0) than those of northern madtoms (76–140, $\bar{x} = 98$, CV = 5.8) but relative fecundity (oocytes/g body weight) was greater for the northern madtom ($\bar{x} = 20.2$, CV = 5.5) than the stonecat ($\bar{x} = 13.5$, CV = 7.5). Although both species exhibited significant relationships ($P < 0.05$) between number of oocytes and SL and ABW, Pearson correlation between SL and clutch size and ABW and clutch size were slightly greater for the stonecat ($r = 0.74$, 0.88) than northern madtom ($r = 0.66$, 0.71).

Diet comparison

Of the 15 macroinvertebrate taxa present in northern madtom stomach contents (Table 2), blackfly (Simulidae), midge (Chironimidae), stonefly (Plecoptera, Perlinella *spp.*), and caddisfly (Trichoptera) larvae comprised the majority of the species' diet in numbers consumed (Figure 2). Based on Strauss' index values, northern madtoms preferred blackfly and stonefly larvae, avoided midge and riffle beetle larvae (Figure 3), and ate the remaining taxa in nearly the same proportion to their relative abundance in the kick sample ($L < |0.10|$).

Stonecats ate fewer macroinvertebrate taxa (13) than northern madtoms and fed primarily on stoneflies, midges, *Dineutus spp.* beetle larvae, and caddisflies. The largest size class of stonecats in French Creek (≥ 130 mm) fed mostly on crayfish, darters (*Etheostoma spp.*) and mayflies, whereas smaller individuals fed exclusively on insect larvae. Stoneflies occurred in all stonecat stomachs smaller than 110 mm ($n = 19$), occurred less frequently (85.7 percent) in 111–130 mm individuals ($n = 7$), and were absent from stonecats larger than 130 mm ($n = 3$). Stonecats preferred stoneflies (L = 0.45) more than northern madtoms did, but ate the most preferred northern madtom prey item (Simulidae) in proportion to its abundance in kick samples (L = 0.00). Aside from differing preference of these two taxa, stonecats and northern madtoms had similar preference for all other food items. Non-macroinvertebrate items found in stonecat stomachs included darters, stones, fish eggs, and vegetation, whereas the northern madtom ate fish eggs and vegetation.

Large stonecat (≥ 91 mm) diet overlapped northern madtom ($C_{xy} = 0.951$) diet, but small stonecats had a more similar diet to similarly-sized northern madtoms ($C_{xy} = 0.964$) than they did to larger stonecats ($C_{xy} = 0.916$). Prey item frequency of occurrence in northern madtom and small stonecat stomachs was similar, but northern madtoms ate more dipterans than small stonecats, whereas stonecats ate more stoneflies. Prey items that stonecats ate but northern madtoms did not included dragonfly larvae, oligochaetes, and darters, whereas northern madtoms ate several taxa (e.g., two mayfly genera, amphipods, and gastropods) that stonecats did not. Elmid beetle larvae were very common in the kick sample (17.4 percent), but were absent from stomach contents of both madtom species. Within the caddisfly family Hydropsychidae, *Ceratopsyche* contributed a low percentage of the food base (1.2 percent) but madtoms ate them more frequently than the closely related and abundant (13.1) *Cheumatopsyche*, resulting in preference for *Ceratopsyche*, and avoidance of *Cheumatopsyche*.

DISCUSSION

Madtom life history studies are often limited in scope because madtom species are frequently imperiled (Burr and Stoeckel, 1999) and protected from collection. Although endangered in Pennsylvania, northern madtoms in this study were collected as state agency vouchers. These collections afforded us the otherwise impossible

TABLE 2. Proportion and Strauss' index (L) values of items found in northern madtom and stonecat stomach contents and the available food base (pooled contents of nine, 20 s D-frame kicknet samples).

Order / Family or genus	Kick sample Percent	Northern madtom Percent	Northern madtom *L*	Stonecat Percent	Stonecat *L*
Diptera					
Chironimidae	34.1	16.9	(−0.17)	18.3	(−0.16)
Simulidae	0.1	30.0	(0.30)	0.6	(0.00)
Atherix	0.1	—	(0.00)	—	(0.00)
Trichoptera					
Hydropsyche	0.2	0.3	(0.00)	1.2	(0.01)
Ceratopsyche	1.2	8.9	(0.08)	7.4	(0.06)
Cheumatopsyche	13.1	7.5	(−0.06)	5.9	(−0.07)
Unidentified pupae	0.6	—		—	
Plectoptera					
Perlinella	1.4	11.4	(0.10)	46.4	(0.45)
Ephemeroptera					
Anthopotamus	0.3	4.2	(0.04)	3.7	(0.03)
Caenis	5.4	—	(−0.05)	—	(0.00)
Baetis	0.2	—	(0.00)	—	(0.00)
Pseudocloeon	0.1	—	(0.00)	—	(0.00)
Unidentifiable larvae	0.1	—	(0.00)	—	(0.00)
Ephoron	8.6	0.8	(−0.08)	—	(−0.09)
Stenacron	0.1	—	(0.00)	—	(0.00)
Stenonema	0.6	1.1	(0.01)	—	(−0.01)
Siphlonisca	0.1	—	(0.00)	—	(0.00)
Ephemerellidae	0.1	—	(0.00)	—	(0.00)
Coleoptera					
Elmid larvae	17.4	—	(−0.17)	—	(−0.17)
Dineutus	0.7	6.4	(0.06)	9.0	(0.08)
Stenelmis	1.1	0.6	(−0.01)	—	(0.00)
Optioservus	0.4	—	(0.00)	—	(0.00)
Psephenus	1.2	7.2	(0.06)	0.3	(−0.01)
Megaloptera					
Corydalus	0.1	—	(0.0)	—	(0.0)
Odonata					
Anisoptera	—	—	(0.00)	0.3	(0.00)
Oligochaeta	9.1	—	(−0.09)	1.5	(−0.08)
Hirudinea	0.4	—	(0.00)	—	(0.00)
Gastropoda					
Pleuroceridae	0.6	0.3	(0.00)	—	(−0.01)
Ferrissia	0.3	—	(0.00)	—	(0.00)
Bivalva					
Corbiculidae	0.1		(0.00)		(0.00)
Sphaeriidae	1.8		(−0.02)		(−0.02)
Crustacea					
Gammarus	0.1	3.6	(0.04)	—	(0.0)
Cambaridae	0.1	0.6	(0.0)	2.8	(0.03)
Other					
Fish eggs	0.3	0.3	(0.0)	1.2	(0.01)
Etheostoma	—	—	(0.0)	1.0	(0.01)

opportunity to gather previously unavailable information regarding fecundity and diet of the northern madtom. Additionally, this study documented potentially important similarities and differences among syntopic madtom species. Prey and general habitat (i.e., riffles) preferences of the stonecat and northern madtom were similar; however, stonecats were on average, nearly 40 percent larger than northern madtoms which resulted in greater stonecat absolute fecundity and potentially important diet differences between the two madtom species.

The unusually high ratio of females to males collected for the northern madtom (9:1) and stonecat (5:1) could have been a result of nesting males being difficult to capture as suggested by Clugston and Cooper (1960) and Mayden and Burr (1981). Although the relationship between stonecat weight and length (Log ABW = −4.78 + 3.00 SL; $r = 0.99$, $n = 24$) was very

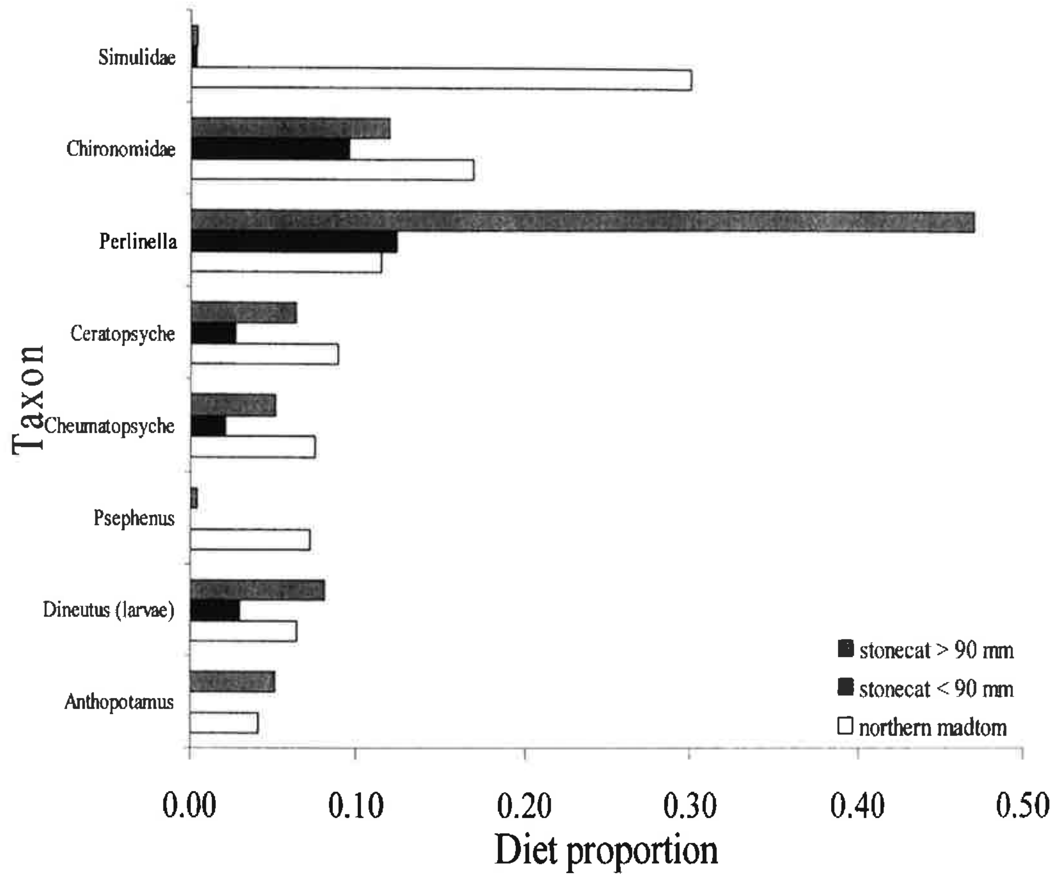

FIGURE 2. Proportion of common (> 5 percent) prey items found in northern madtom, similarly-sized stonecat (< 90 mm), and large stonecat (> 90 mm) stomach contents in terms of numbers consumed.

similar to that reported for stonecats in Illinois streams (LogW = −4.91 + 3.04SL, Walsh and Burr, 1985), mature female stonecats in French Creek were slightly smaller ($\bar{x}$ = 112.8, SD = 11.7) than those in Illinois streams ($\bar{x}$ = 119.4; Walsh and Burr, 1985). Age at reproductive maturity (≥ 3 y) estimates between Illinois (Walsh and Burr, 1985) and French Creek were similar; however, French Creek stonecat clutch sizes were much smaller than those of Lake Erie ($\bar{x}$ = 973, 767–1205; Langlois, 1954) and Illinois streams ($\bar{x}$ = 377.8, 189–570; Walsh and Burr, 1985).

The stonecat and northern madtom have similar spawning behavior and habitat (i.e., spawning in cavities or under stones during spring and summer; Taylor, 1969; Pfingsten and Edds, 1994; Burr and Stoeckel, 1999). Although largely unstudied (Burr and Stoeckel, 1999), factors suggested for partitioning of madtom spawning microhabitat include spawning time and body size (Clark, 1978). A greater proportion (73 percent) of northern madtom females contained maturing oocytes than age 3 or older (reproductively mature) stonecat females (56 percent), but because ictalurids do not consistently deposit their eggs immediately after maturation (Burr and Stoeckel, 1999), it cannot be said that they spawn at different times in French Creek. Most mature northern madtom and stonecat specimens were collected from one large riffle, which suggested that they were preparing to spawn near one another. No age 3 stonecats, however, overlapped the size of mature northern madtoms (60.9–85.2 mm); thus, if the madtom species do spawn simultaneously as suggested by this study, the relatively small, mature northern madtom females are able to use smaller cavities than much larger stonecat females do. Northern madtom diet was undocumented prior to this study, but French Creek stonecats had similar diets to those from Illinois populations (Walsh and Burr, 1985). Both madtom species were primarily generalist in their feeding habits (consumed most prey in proportion to their relative abundance in the environment); however, based upon overall comparison of northern madtom and stonecat diet selectivity (all size classes), the most preferred prey of each species was ingested much less frequently by the other madtom species. Although blackflies were rare in the environment (0.1 percent of pooled kick samples), they accounted for 30 percent of northern madtom prey items; conversely, stonecats rarely ate blackflies, which resulted in very different preferences

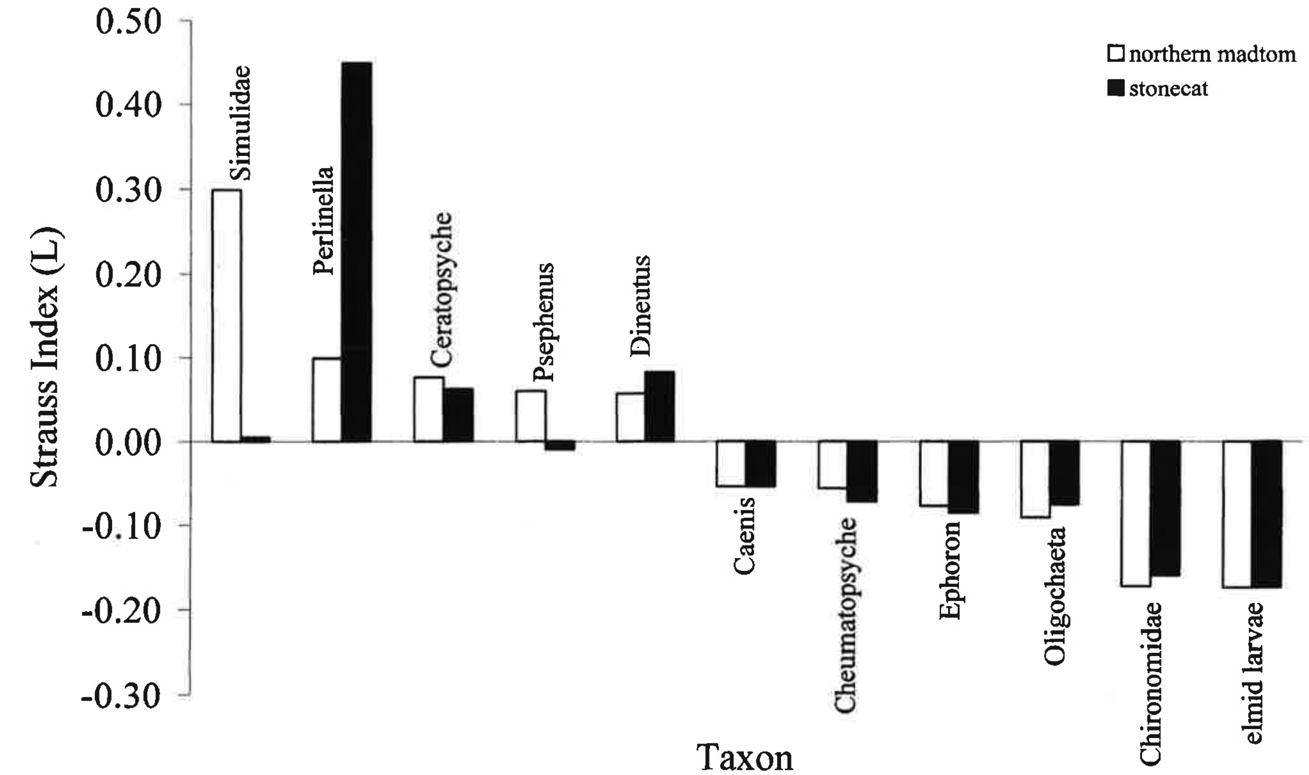

FIGURE 3. Strauss' index (L) values indicating preferred and avoided food items of northern madtoms and stonecats. Taxa that madtoms ate in equal proportion to their abundance in the environment ($L \leq |0.05|$) were not included in this figure.

for blackflies by the two madtom species. Stoneflies were also rare in the kick samples (1.4 percent), but accounted for a larger portion of stonecat diet (46.4 percent) than that of northern madtoms (11.4 percent). Small stonecats had a more similar diet to northern madtoms than large stonecats did, suggesting similar resource use by young stonecats and northern madtoms. Diet overlap between madtom species declined as stonecats grew (> 90 mm) primarily because stoneflies were more prevalent in large stonecat stomach contents. Additionally, small stonecats had a more similar diet to northern madtoms (C_{xy} = 0.964) than they did to larger individuals of their own species (C_{xy} = 0.916), which further illustrated the preference for large prey items by larger stonecats.

Northern madtoms and stonecats similarly preferred several rare prey items and avoided some common prey, which suggested that primarily generalist feeders can be selective. Both madtom species apparently differentiated among three closely related (Hydropsychidae) caddisfly genera and consumed them at different levels of preference. *Hydropsyche* was rare in the environment and eaten infrequently. The more abundant *Ceratopsyche* was a preferred item for both northern madtoms and stonecats, whereas the most abundant caddisfly genus, *Cheumatopsyche* was avoided by both madtom species. Although these caddisflies are similar in habit, color, morphology, and size (Merrit and Cummins, 1996), both madtoms preferred *Ceratopsyche* more than the other caddisfly genera. Riffle beetles are very common in riffle habitats (Merrit and Cummins, 1996) and accounted for the second largest proportion (17.4 percent) of the pooled kick samples; however, neither madtom species consumed riffle beetle larvae. Riffle beetles may have been unpalatable to madtoms or unavailable at the microhabitat scale. We collected the majority of madtom specimens from below a large riffle; consequently, several macroinvertebrate taxa (*Caenis*, *Ephoron*, *Oligochaeta*, and *Chironimidae*) that both madtom species ate in relatively low proportions may have been unavailable because these invertebrates are typically found in slow moving pools (Peckarsky et al., 1990, Merrit and Cummins, 1996).

The stonecat likely exists syntopically with rare and smaller madtoms (e.g., northern madtom) in many systems. Much is still unknown regarding interspecific interactions among madtoms; however, our results suggest stonecat competition with smaller madtoms for nesting sites is unlikely because 1) the larger size of mature stonecats than mature northern madtoms requires larger spawning cavities or, 2) small stonecats spawn later in the season than similarly-sized northern madtoms. Similarly, as stonecats outgrow the size range of smaller madtom species such as the northern madtom, they tend to feed primarily on larger prey organisms.

The stonecat is extending its already wide distribution (Buchanan, 1973; Royer and Anderson, 1977; Platania et al., 1986) due in part to its longevity, "considerable environmental plasticity" (McCulloch and Stewart 1998, p. 217) and reproductive capability. Conversely, the northern madtom is imperiled as a consequence of its similarities (i.e., relatively small body size, short-lived, low fecundity, disjunct geographic range) to federally threatened (Neosho *N. placidus*, yellowfin *N. flavipinnis*) and endangered (pygmy *N. stanauli*, Scioto *N. trautmani*, smoky *N. baileyi*) madtoms in North America. Size differences may enable typically small and rare madtoms to occur syntopically with larger potential competitors; however, the relatively low fecundity and geographic isolation of imperiled madtoms render them less capable of withstanding human-induced disturbances. Because of their unique character and vulnerability, conservation of isolated madtom populations (e.g., the northern madtom in French Creek) requires continued protection and study.

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WOODY PLANT INVASION AND THE IMPORTANCE OF ANTHROPOGENIC DISTURBANCE WITHIN XERIC LIMESTONE PRAIRIES[1]

DANIEL C. LAUGHLIN[2]

Interdepartmental Graduate Degree Program in Ecology,
208 Mueller Laboratory, The Pennsylvania State University, University Park, Pennsylvania 16802

ABSTRACT

Disturbance plays an important ecological role in determining the structure and species composition of grassland communities. Xeric limestone prairies, a rare and threatened habitat in Pennsylvania, are currently being invaded by woody species, such as *Juniperus virginiana* (Eastern red-cedar), *Elaeagnus umbellata* (autumn olive), *Lonicera* spp. (honeysuckles), and *Crataegus* spp. (hawthorns). Woody plant invasion threatens the long-term persistence of the 10 known remaining limestone prairies in Pennsylvania. Repeat aerial photographs were rectified in a Geographical Information System and were used to calculate rates of woody plant invasion within two limestone prairies in central Pennsylvania. The average invasion rate from 1949 to 1994 was 1,350 m^2/year in the Great Plains prairie and 325 m^2/year in the Westfall Ridge Prairie Preserve (The Nature Conservancy). Extremely droughty soils are a major impediment to rapid woody invasion and are the sole contributors to prairie maintenance at present. Historically, however, Indian-set fires and other anthropogenic disturbances promoted establishment and maintenance of xeric limestone prairies. Agricultural activities, such as plowing and livestock grazing (and associated soil erosion), forest clearing, and quarrying activities may have opened up areas for colonization by prairie species. This study highlights the importance of exogenous disturbances in determining xeric limestone prairie structure and species composition and suggests management strategies for restoring and maintaining the threatened prairies of Pennsylvania.
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[1]Submitted for publication 24 June 2003; accepted 29 August 2003.
[2]Current Address: Ecological Restoration Institute, Northern Arizona University, P.O. Box 15017, Flagstaff, Arizona 86011. Email: Daniel.Laughlin@nau.edu

INTRODUCTION

Ecological disturbances are ubiquitous in nature and are important for virtually every ecosystem that has been studied (White 1979, Vogl 1980, Bazzaz 1983, Sousa 1984, Pickett and White 1985). Many forms of disturbances influence the landscape at different temporal and spatial scales (Denslow 1985, Romme et al. 1998). Sousa (1984) differentiated physical disturbances, such as floods, fires and wind, from biological disturbances, such as grazing and predation. Romme et al. (1998) discussed the differences between large, infrequent disturbances, such as tornados, hurricanes and crown-fires, from small, frequent disturbances, such as windthrows and low-intensity fires. Denslow (1985) highlighted differences between "natural" disturbances (e.g., floods) and "exotic" disturbances (e.g., human activities such as clearcuts and swidden agriculture). Bradshaw and Marquet (2003) reviewed the powerful influence of human disturbance in the Americas, and Russell (1997) demonstrated that species and community distributions are largely determined by past human land use. "Natural" disturbances have increasingly been viewed as important processes in many ecosystems, but anthropogenic disturbances are generally thought of as negative and erosive to ecological integrity (see Mooney and Godron 1983). Anthropogenic disturbances are typically associated with exploitative endeavors, such as timber harvesting and strip mining. Though these types of activities are surely devastating to forested landscapes, other anthropogenic activities such as prescribed burning, forest clearing and livestock grazing can be beneficial for certain habitats, especially grasslands.

Disturbance in grasslands can take many forms. Two broadly defined categories of disturbance in grasslands are 1) changes in soil conditions, and 2) defoliation regimes (van Andel et al. 1987). The former includes altered nutrient, water, and soil availability, and the latter includes altered frequencies of defoliation by grazing, cutting, or burning. Both forms of disturbance

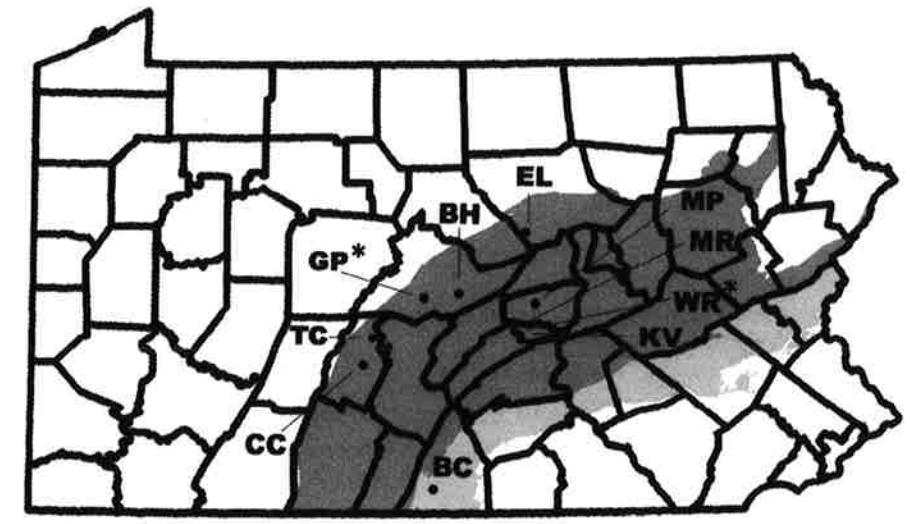

FIGURE 1. Known locations of xeric limestone prairies in Pennsylvania. Asterisks denote the two prairies used in this study. The shading represents the Ridge and Valley Physiographic Province with dark gray representing the Appalachian Mountain Section and light gray the Great Valley Section (Berg et al. 1989). GP = Great Plains prairie, BH = Big Hollow Limestone Prairie, TC = Tytoona Cave, CC = Canoe Creek State Park, WR = Westfall Ridge Prairie, MR = McAlisterville Ridge Rock, KV = Kurtz Valley Ridge, BC = Baker Caverns, MP = Missionary Prairie, EL = Eiswert Limestone Prairie.

influence community structure in the xeric limestone prairies of Pennsylvania.

Xeric limestone prairies are a rare and threatened habitat in the northeastern United States (Laughlin and Uhl, in press). They have been documented in the Missouri Ozarks (Steyermark 1940, Kucera and Martin 1957, Baskin et al. 1994, Baskin and Baskin 2000), Indiana (Bacone et al. 1983), Illinois (Kurz 1981), Virginia, Tennessee, Georgia (DeSelm 1993), Alabama (Harper 1920, DeSelm 1993), Ohio (Braun 1928), West Virginia (Bartgis 1993), and recently in Pennsylvania (Laughlin and Uhl, in press). Proper management of these unique natural areas hinges on an adequate understanding of the ecological processes required to maintain prairie structure and species diversity.

Woody plant encroachment, often by *Juniperus virginiana* (eastern red-cedar), has been identified as the most important threat to limestone prairie persistence throughout the East and Midwest (Harper 1920, Beilmann and Brenner 1951, Kimmel and Probasco 1981, Guyette and McGinnes 1982, Annala et al. 1983, Annala and Kaputska 1983, DeSelm 1989, Lowell and Astroth 1989, Bartgis 1993, DeSelm 1994, Ware 2002, Laughlin and Uhl, in press). Dry and shallow edaphic conditions are believed to inhibit woody plant recruitment in xeric limestone prairies (Kucera and Martin 1957, DeSelm et al. 1969, Annala et al. 1983, Ware 2002). Indeed, without the extremely dry, rocky limestone soils present in the limestone prairies of Ohio, West Virginia, and Pennsylvania (Braun 1928, Bartgis 1993, Laughlin and Uhl, in press), these few remnant prairies would likely have succeeded to forest. However, xeric limestone prairie structure is also believed to be maintained by anthropogenic disturbances, such as Indian-set fires, forest clearing, and soil erosion associated with agricultural activities (Baskin et al. 1994, Baskin and Baskin 2000, J.M. Baskin and C.C. Baskin, pers. comm.). Since woody plants have always encroached into limestone prairies, it is apparent that endogenous factors, such as edaphic conditions, cannot be the only driving processes in these small prairie systems.

The objective of this study was to quantify the rate of woody plant invasion within two xeric limestone prairies in Pennsylvania by utilizing repeat aerial photographs and a Geographical Information System (GIS). The rate of woody plant invasion is a function of the magnitude and frequency of disturbance to the vegetation (Sousa 1984). Therefore, I discuss the interactions between woody plant invasion and several forms of anthropogenic disturbances in xeric limestone prairies in Pennsylvania. A secondary objective was to conduct floristic inventories of the Great Plains and Westfall Ridge prairies to determine current plant species assemblages and to calculate what percentage of the flora was exotic.

STUDY AREA

Xeric limestone prairies in Pennsylvania are found exclusively in the central counties within the Ridge and Valley Physiographic Province (Figure 1). Historical accounts describe presettlement grasslands in the valleys of central Pennsylvania. In 1775, Philip Vickers Fithian

TABLE 1. Relationships of xeric limestone prairies in Pennsylvania with physiographic features and with known anthropogenic disturbances. IND = moisture availability index (see Methods). An "X" denotes a factor that influences the vegetation at each limestone prairie.

	Physiographic Features			Anthropogenic Disturbances & Management Influences					
Xeric limestone prairie	Aspect (°) Gen. Direction[1]	Slope (%)[1]	IND	Near a Limestone Ledge	Agricultural Plowing (nearby)	Grazing History	Fire Suppression	Quarry (nearby)	ROW[2]
Great Plains Remnant	195, S-SW	14	−3.5	X[3]	X	X	X		
Big Hollow Prairie	210, S-SW	14	−3.9		X	?[4]	X		X
Eiswert Limestone Prairie	235, SW	19	−3.9	X			X	X	
Missionary Prairie	260, W-SW	27	−3.3	X	X	?	X	X	
McAlisterville Ridge Rock	265, W-SW	55	−3.0				X		
Westfall Ridge Prairie	210, S-SW	31	−3.9	X	X	?	X	X	
Kurtz Valley Ridge	120, SE	9	0.7		X	?	X		X
Tytoona Cave	180, S	29	−2.8		X	?	X		X
Canoe Creek	255, SW-W	32	−3.5	X			X	X	
Baker Caverns	255, SW-W	12	−3.5		X	?	X	X[5]	X[5]

[1]Data from Laughlin and Uhl (in press)
[2]"Powerline Right-of-Ways"
[3]Railroad cut through limestone
[4]Question marks signify that livestock grazing was a possible or likely disturbance
[5]See Klotz and Walck (1993).

wrote, "In [Penns Valley] there are large open plains, cleared either by Indians or accidental fire. Hundreds of acres are covered with fine grass and a great variety of flowers" (Albion and Dodson 1934). In 1794, an "unknown Englishman" wrote, "Soon after we had crossed pens Creek, we came into some land with no timber for several miles called potters plains pretty fowrish (sic) good land but much wanting of watter" (Miller 1996). The 10 known remnant prairies are found in the limestone valleys on south-southwest facing slopes (Table 1) and some are found near limestone ledges [see also Table 2 in Baskin et al. (1994)], which are indicative of the dry and exposed environment. Limestone prairies throughout the East and Midwest are often on steep to gently sloping hillsides with south-southwest aspects (Annala and Kaputska 1983, Bacone et al. 1983, DeSelm 1989, Lowell and Astroth 1989, Bartgis 1993, Baskin et al. 1994, Ware 2002). All the Pennsylvania prairies are small (< 0.2 ha), and most are found on the Opequon soil series (Laughlin and Uhl, in press). The Opequon soil series is characterized by shallow, rocky, clay loams underlain by limestone bedrock, which is often exposed at the surface (Braker 1981). Soils data for individual prairies can be found in Laughlin and Uhl (in press). Limestone prairies throughout the East and Midwest are characterized by shallow soils (DeSelm et al. 1969, DeSelm 1989, 1993, Baskin et al. 1994), which can have mean depths as low as 3.9 cm (Bartgis 1993) and 12.2 cm (Kucera and Martin 1957).

Bouteloua curtipendula, which is listed as threatened in Pennsylvania, is the dominant graminoid in xeric limestone prairies in Pennsylvania and West Virginia (Bartgis 1993, Laughlin and Uhl, in press). The most common native forbs in the prairies include *Anemone virginiana, Solidago nemoralis, Monarda fistulosa, Lithospermum canescens, Asclepias tuberosa, A. verticillata, A. viridiflora*, and *Penstemon hirsutus* (nomenclature follows Rhoads and Block [2000]). The most common native woody species surrounding these prairies are *Juniperus virginiana, Juglans nigra, Celtis occidentalis, Pinus strobus*, and *P. virginiana*. Eleven other rare, state-listed species occur on limestone prairies throughout central Pennsylvania, including *Anemone cylindrica, Bromus kalmii, Linum sulcatum, Lithospermum canescens, Onosmodium molle* var. *hispidissimum, Ophioglossum engelmannii, Panicum oligosanthes, Ranunculus fascicularis, Ruellia humulis, Senna marilandica*, and *Solidago rigida* (Laughlin and Uhl, in press).

Two limestone prairies were chosen for this study based on their historical significance and conservation priority. One of the remnants chosen was the Great Plains prairie in Penn's Valley, Centre County, Pennsylvania (UTM Zone 18, 279562 E, 4524674 N) since it is part of a limestone prairie that was extensive in presettlement times (Losensky 1961, Macneal 1998, Ruffner and Arabas 2000, Laughlin and Uhl, in press). The majority of the remnant was in a forest opening on a gentle (14% slope) south-southwest (195°) facing slope (Table 1). The other remnant chosen was The Nature Conservancy's Westfall Ridge Prairie Preserve in Juniata County, Pennsylvania (UTM Zone 18, 309168 E, 4498828 N) since it is the only actively managed limestone prairie preserve in Pennsylvania (G. Gress, The Nature Conservancy of Pennsylvania, pers. comm.). This prairie preserve is on a fairly steep (31% slope) south-southwest facing (210°) hillside (Table 1).

METHODS

I obtained six aerial photographs of each prairie remnant, one from every decade from the 1940s to the 1990s. Scanned images of the aerial photos were digitally rectified in ArcInfo to correct for distortion so that land areas could be accurately measured. In ArcView 3.2, I digitally measured the areas of grassland for each photo. Grassland was defined as treeless open land within the confines of defined property boundaries that did not display any evidence of agricultural use. Land was considered to be agricultural if geometric lines or curves indicative of plowing were visible on the photos (Figure 2). Areas defined to be former prairie were ground-truthed in the field to ensure accuracy by conducting floristic surveys. A few prairie species persisted, rather weakly, in the early successional forests surrounding the prairies (Figure 2).

TABLE 2. Native and exotic plant species within and immediately surrounding the Great Plains (GP) prairie remnant and the Westfall Ridge (WR) Prairie Preserve in 2001. Origin refers to whether the taxon is native to Pennsylvania (N) or introduced (I). An "x" denotes that a species was present in a prairie, an "h" denotes that it was detected in the past by botanists from the Pennsylvania Natural Diversity Inventory (Wiegman 1986, Smith 1987, Kunsman 1990). Nomenclature follows Rhoads and Block (2000).

Family Species	Common name	Growth form	Origin	GP	WR
Anacardiaceae					
Rhus aromatica Aiton	Aromatic sumac	Shrub	N	x	x
Rhus typhina L.	Staghorn sumac	Shrub	N	-	x
Apiaceae					
Bupleurum rotundifolium L.	Thoroughwax	Forb	I	-	x
Daucus carota L.	Queen Anne's-lace	Forb	I	x	x
Osmorhiza longistylis (Torr.) DC.	Aniseroot	Forb	N	x	x
Sanicula canadensis L.	Snakeroot	Forb	N	-	x
Taenidia integerrima (L.) Drude	Yellow pimpernel	Forb	N	x	-
Zizia aptera (A.Gray) Fernald	Golden-alexander	Forb	N	x	-
Apocynaceae					
Apocynum cannabinum L.	Indian-hemp	Forb	N	x	x
Asclepiadaceae					
Asclepias tuberosa L.	Butterfly-weed	Forb	N	x	x
Asclepias verticillata L.	Whorled milkweed	Forb	N	x	x
Asclepias viridiflora Raf.	Green milkweed	Forb	N	x	x
Asteraceae					
Achillea millefolium L.	Yarrow	Forb	I	x	-
Ambrosia artemisiifolia L.	Common ragweed	Forb	N	-	x
Ambrosia trifida L.	Giant ragweed	Forb	N	x	-
Antennaria neglecta Greene	Overlooked pussytoe	Forb	N	x	-
Arctium minus (Hill) Bernh.	Common burdock	Forb	I	x	x
Aster ericoides L.	White heath aster	Forb	N	h	-
Aster laevis L.	Smooth blue aster	Forb	N	x	x
Aster lateriflorus (L.) Britton.	Calico aster	Forb	N	x	-
Aster pilosus Willd.	Heath aster	Forb	N	x	x
Aster urophyllus Lindl. in DC.	Aster	Forb	N	x	-
Brickellia eupatorioides (L.) Shinners	False boneset	Forb	N	x	x
Centaurea maculosa Lam.	Spotted knapweed	Forb	I	-	x
Chrysanthemum leucanthemum L.	Ox-eye daisy	Forb	I	x	x
Cirsium arvense (L.) Scop.	Canada thistle	Forb	I	-	x
Cirsium discolor (Muhl.) Spreng.	Field thistle	Forb	N	x	x
Cirsium vulgare (Savi) Ten.	Bull thistle	Forb	I	-	x
Eupatorium altissimum L.	Tall eupatorium	Forb	N	x	-
Eupatorium rugosum Houtt.	White-snakeroot	Forb	N	-	x

(Continued)

TABLE 2. (Continued).

Helianthus decapetalus L.	Thin-leaved sunflower	Forb	N	-	x
Helianthus divaricatus L.	Rough sunflower	Forb	N	x	-
Hieracium caespitosum Dumort.	King-devil	Forb	I	x	-
Lactuca canadensis L.	Wild lettuce	Forb	N	-	x
Senecio obovatus Muhl.	Ragwort	Forb	N	-	x
Solidago juncea Aiton	Early goldenrod	Forb	N	x	x
Solidago nemoralis Aiton	Gray goldenrod	Forb	N	x	x
Solidago rigida L.	Stiff goldenrod	Forb	N	x	-
Taraxacum officinale L.	Dandelion	Forb	I	x	x
Tragopogon dubius Scop.	Yellow goatsbeard	Forb	I	x	x
Boraginaceae					
Lithospermum canescens (Michx.) Lehm.	Hoary puccoon	Forb	N	x	x
Onosmodium molle Michx. var. *hispidissimum* (Mack.)I.M.Johnst.	Marble-seed	Forb	N	x	x
Betulaceae					
Corylus americana Walter	American hazelnut	Tree	N	h	x
Brassicaceae					
Alliaria petiolata (M.Bieb.) Cavara & Grande	Garlic mustard	Forb	I	x	x
Arabis laevigata (Muhl. ex Willd.) Poir.	Smooth rockcress	Forb		-	x
Caesalpinaceae					
Cercis canadensis L.	Red bud	Tree	N	x	x
Campanulaceae					
Campanula americana L.	Tall bellflower	Forb	N	x	x
Caprifoliaceae					
Lonicera mackii (Rupr.) Maxim.	Amur honeysuckle	Shrub	I	x	x
Lonicera morrowii A.Gray	Morrow's honeysuckle	Shrub	I	x	x
Triosteum aurantiacum E.P.Bicknell	Wild-coffee	Forb	N	x	x
Viburnum rafinesquianum Schult.	Downy arrow-wood	Shrub	N	h	x
Convolvulaceae					
Calystegia spithamaea (L.)Pursh	Low bindweed	Forb	N	x	h
Cornaceae					
Cornus racemosa Lam.	Silky dogwood	Shrub	N	x	-
Cuppresaceae					
Juniperus virginiana L.	Eastern red-cedar	Tree	N	-	x
Cyperaceae					
Carex amphibola Steud.		Sedge	N	x	-
Carex blanda Dewey		Sedge	N	x	-
Carex bushii Mack.		Sedge	N	x	-
Carex cephalophora Willd.		Sedge	N	x	-
Carex hirsutella Mack.		Sedge	N	x	-
Carex spp.		Sedge	N	-	x
Eleagnaceae					
Eleagnus umbellata Thunb.	Autumn olive	Shrub	I	x	-
Euphorbiaceae					
Euphorbia corollata L.	Flowering spurge	Forb	N	x	-
Fabaceae					
Desmodium cuspidatum (Muhl. ex Willd.) Loudon	Tick-trefoil	Forb	N	-	x
Desmodium rotundifolium DC.	Round-leaved tick-trefoil	Forb	N	-	h
Medicago lupulina L.	Black medic	Forb	I	x	-

(Continued)

TABLE 2. (Continued).

Melilotus alba Medik.	White sweet-clover	Forb	I	-	x
Melilotus officinalis (L.) Pall.	Yellow sweet-clover	Forb	I	-	x
Trifolium pratense L.	Red clover	Forb	I	x	x
Trifolium repens L.	White clover	Forb	I	x	-
Fagaceae					
Quercus alba L.	White oak	Tree	N	-	x
Quercus prinoides Willd.	Dwarf chestnut oak	Tree	N	h	-
Quercus rubra L.	Northern red oak	Tree	N	-	x
Iridaceae					
Sisrynchium montanum Greene	Blue-eyed-grass	Forb	N	x	-
Juglandaceae					
Carya glabra (Mill.) Sweet	Pignut hickory	Tree	N	-	x
Carya tomentosa (Lam. ex Poir.) Nutt.	Mockernut hickory	Tree	N	-	x
Juglans nigra L.	Black walnut	Tree	N	x	x
Lamiaceae					
Clinopodium vulgare L.	Wild basil	Forb	I	x	x
Monarda fistulosa L.	Wild bergamot	Forb	N	x	x
Nepeta cataria L.	Catnip	Forb	I	-	x
Prunella vulgaris L.	Heal-all	Forb	I	x	x
Pycnanthemum muticum (Michx.) Pers.	Mountain-mint	Forb	N	x	x
Pycnanthemum virginianum (L.) Durand & Jacks. ex B.L.Rob. & Fernald	Mountain-mint	Forb	N	-	x
Scutellaria elliptica Muhl. ex Spreng.	Hairy skullcap	Forb	N	-	h
Scutellaria incana Biehler	Downy skullcap	Forb	N	x	-
Trichostema brachiatum L.	False pennyroyal	Forb	N	h	-
Liliaceae					
Allium cernuum Roth	Nodding onion	Forb	N	x	x
Linaceae					
Linum sulcatum Riddell	Grooved yellow flax	Forb	N	x	-
Onagraceae					
Gaura biennis L.	Gaura	Forb	N	x	-
Oenothera biennis L.	Evening-primrose	Forb	N	-	x
Orchidaceae					
Spiranthes lacera (Raf.) Raf. var. *gracilis* (Bigelow) Luer	Northern slender ladies'-tresses	Forb	N	x	-
Oxalidaceae					
Oxalis stricta L.	Common yellow wood-sorrel	Forb	N	x	x
Pinaceae					
Pinus pungens Lamb.	Table-mountain pine	Tree	N	-	x
Pinus strobus L.	Eastern white pine	Tree	N	x	-
Pinus virginiana Mill.	Virginia pine	Tree	N	-	x
Plantaginaceae					
Plantago lanceolata L.	English plantain	Forb	I	x	-
Poaceae					
Andropogon gerardii Vitman	Big bluestem	Grass	N	h	-
Bouteloua curtipendula (Michx.) Torr.	Sideoats grama	Grass	N	x	x
Bromus kalmii A.Gray	Prairie brome	Grass	N	x	-
Bromus inermis Leyss.	Smooth brome	Grass	I	x	x
Danthonia spicata (L.) P.Beauv. ex Roem. & Schult.	Poverty grass	Grass	N	x	-

(Continued)

TABLE 2. (Continued).

Elymus hystrix L.	Bottlegrush-grass	Grass	N	x	-
Elymus trachycaulus (Link) Gould ex Shinners	Slender wheatgrass	Grass	N	h	-
Festuca elatior L.	Fescue	Grass	I	x	x
Panicum acuminatum Sw.	Panic grass	Grass	N	x	-
Panicum linearifolium Scribn.	Panic grass	Grass	N	x	-
Panicum oligosanthes Schult.	Heller's witchgrass	Grass	N	x	-
Phleum pratense L.	Timothy	Grass	I	x	-
Poa compressa L.	Canada bluegrass	Grass	I	-	x
Poa pratensis L.	Kentucky bluegrass	Grass	I?	x	-
Schizachyrium scoparium (Michx.) Nash	Little bluestem	Grass	N	h	-
Sorghastrum nutans (L.) Nash	Indian grass	Grass	N	x	-
Sporobolus asper (Michx.) Kunth	Dropseed	Grass	N	h	-
Polygalaceae					
Polygala senega L.	Seneca snakeroot	Forb	N	x	-
Polypodiaceae					
Asplenium platyneuron (L.) Britton, Stearns & Poggenb.	Ebony spleenwort	Fern	N	x	x
Ranunculaceae					
Anemone cylindrica A.Gray	Long-headed anemone	Forb	N	x	-
Anemone virginiana L.	Thimbleweed	Forb	N	x	x
Aquilegia canadensis L.	Wild columbine	Forb	N	x	-
Ranunculus fascicularis Muhl. ex J.M.Bigelow	Early buttercup	Forb	N	x	-
Thalictrum dioicum L.	Early meadow-rue	Forb	N	x	-
Thalictrum revolutum DC.	Purple meadow-rue	Forb	N	h	-
Rosaceae					
Agrimonia pubescens Wallr.	Downy agrimony	Forb	N	h	x
Crataegus spp.	Hawthorns	Trees	N/I?	x	-
Fragaria virginiana Mill.	Wild strawberry	Forb	N	x	-
Geum canadensis L.	White avens	Forb	N	x	x
Malus coronaria (L.) Mill.	Sweet crabapple	Tree	N	x	-
Prunus serotina Ehrh.	Wild black cherry	Tree	N	x	x
Rosa carolina L.	Pasture rose	Shrub	N	-	x
Rosa multiflora Thunb. ex Murray	Multiflora rose	Shrub	I	x	-
Rubus occidentalis L.	Black raspberry	Shrub	N	x	x
Rubus pensilvanicus Poir.	Blackberry	Shrub	N	x	-
Rubiaceae					
Galium circaezans Michx.	Wild licorice	Forb	N	-	h
Galium pilosum Aiton	Bedstraw	Forb	N	x	-
Galium triflorum Michx.	Sweet-scented bedstraw	Forb	N	x	-
Scrophulariaceae					
Linaria vulgaris Hill	Butter-and-eggs	Forb	I	x	-
Penstemon hirsutus (L.) Willd.	Northeastern beardtongue	Forb	N	x	x
Verbascum thapsus L.	Common mullein	Forb	I	-	x
Veronica officinalis L.	Common speedwell	Forb	I	x	-
Solanaceae					
Physalis heterophylla Nees	Clammy ground-cherry	Forb	N	x	-
Solanum carolinense L.	Horse-nettle	Forb	N	x	-
Ulmaceae					
Celtis occidentalis L.	Hackberry	Tree	N	-	x
Ulmus rubra L.	Slippery elm	Tree	N	-	x

(Continued)

TABLE 2. (Continued).

Violaceae					
Viola sororia Willd.	Common blue violet	Forb	N	x	x
Vitaceae					
Parthenocissus quinquefolia (L.) Planch.	Virginia-creeper	Vine	N	x	x
Vitis aestivalis Michx.	Summer grape	Vine	N	x	-

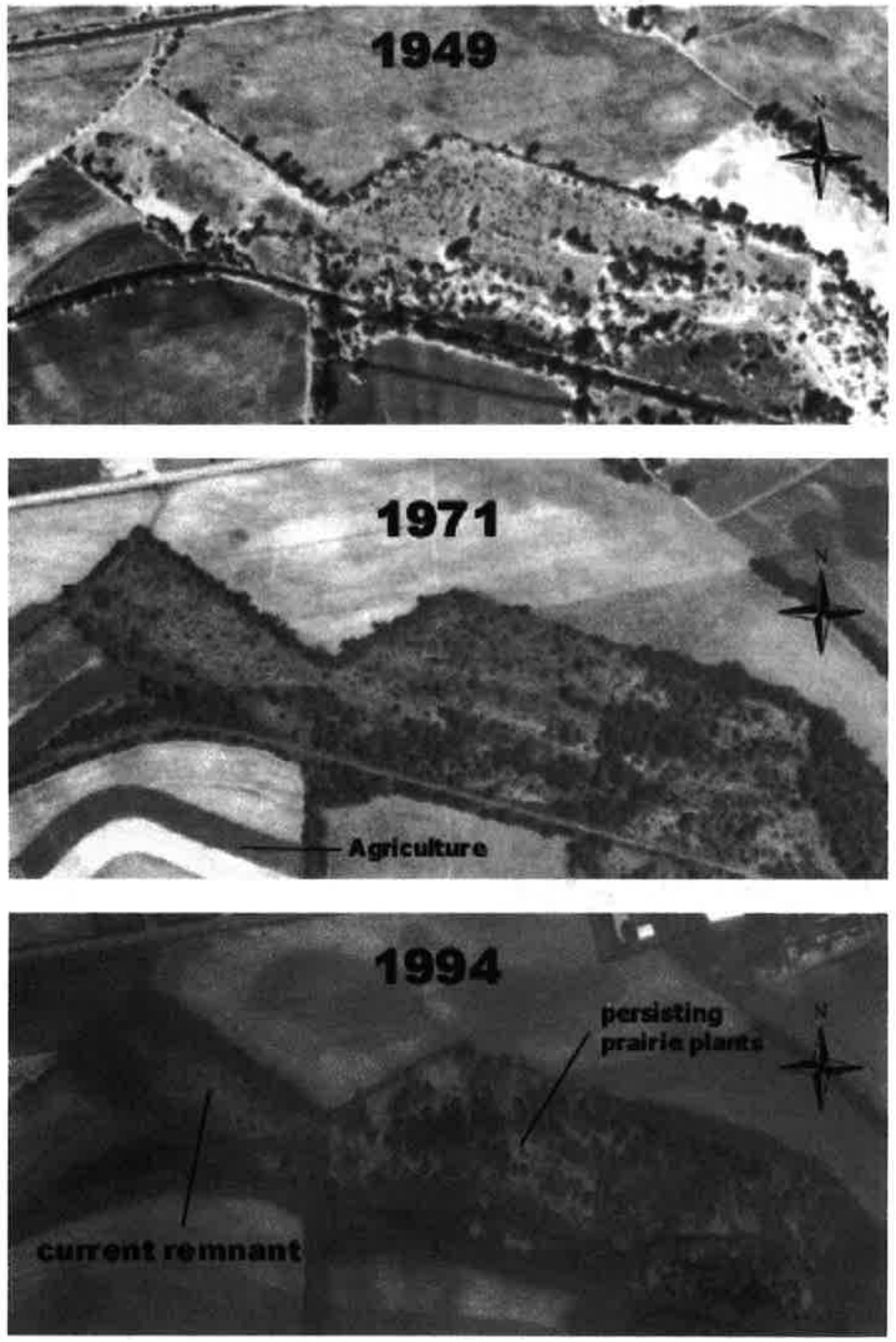

FIGURE 2. Woody plant invasion in the Great Plains prairie remnant, Penns Valley, Centre County, in central Pennsylvania from 1949 to 1994. Photos from 1957 and 1989 are not shown. Evidence of agriculture, which is indicated in the 1971 photo, is present surrounding the site.

An index of moisture availability (IND), developed by Pallardy (1995; cited in Batek et al. 1999), was calculated for each of the 10 known limestone prairies in Pennsylvania based on percent slope and aspect in degrees. The equation used was

$$\text{IND} = [\text{cosine}\,(\text{aspect-45})\times\text{slope category}].$$

The following slope categories were used: 0(< 1%), 1 (1 − 2.15%), 2 (2.16 − 4.64%), 3 (4.65 − 10%), 4 (> 10%). Therefore, the index ranges from −4 (very xeric) to +4 (very mesic). This index gives a general impression of the dryness of the prairies based only on slope and aspect.

Evidence of anthropogenic disturbance was sought for at each of the 10 prairies. Grazing and plowing histories were assessed by looking at current use of adjacent land and by speaking with local residents. Nearby quarrying activities and the presence of a powerline right-of-way were also noted.

Floristic inventories of the Great Plains and Westfall Ridge prairie were conducted in 2001. Both sites were visited at least three times (late spring, mid-summer, and fall). Every species within and immediately surrounding the prairies were included in the inventory. The lists from the current survey were compared with lists compiled by botanists from the Pennsylvania Natural Diversity Inventory (PNDI) (Wiegman 1986, Smith 1987, Kunsman 1990).

RESULTS

The areal extent of the limestone prairie remnants has declined considerably since the 1940s due to rapid invasion by woody plants. The Great Plains prairie remnant had declined from 77,824 m^2 in 1949 to 17,057 m^2 in 1994 (Figure 2) at a rate of approximately 1,350 m^2/year (Figure 3). In 2001, the remnant was even smaller because of continued invasion since 1994 (Laughlin, D.C., pers. obs.). The most common woody plants that have invaded the Great Plains prairie were *Elaeagnus umbellata, Lonicera morrowii, Lonicera mackii, Crateagus* spp., *Cornus racemosa*, and *Pinus strobus* (Table 2). *Juniperus virginiana* was not a dominant member of the woody flora surrounding the Great Plains prairie. The average rate of invasion was roughly constant from 1949 to 1989 at 1,226 m^2/year, but it increased drastically between 1989 and 1994 to 2,347 m^2/year, nearly double the previous rate.

The Westfall Ridge prairie declined from 15,931 m^2 in 1949 to 1,294 m^2 in 1994 (Figure 4), a rate of approximately 325 m^2/year (Figure 3). The most common woody plants that invaded the Westfall Ridge prairie were *Juniperus virginiana, Lonicera spp., Quercus* spp., and *Pinus* spp. (Table 2). The average rate of encroachment was roughly constant from 1949 to 1970 at 534 m^2/year, but it decreased drastically between 1970

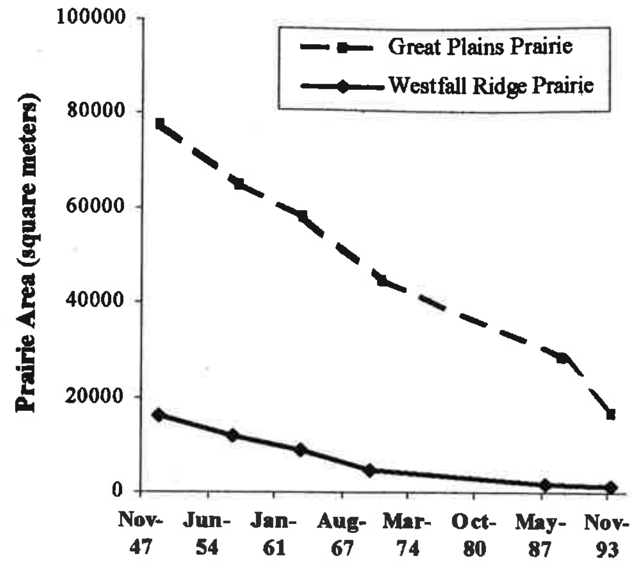

FIGURE 3. Decline of grassland area after 45 years of woody plant invasion in the Great Plains Remnant and the Westfall Ridge Prairie in central Pennsylvania.

and 1994 to 142 m^2/year. This slowed pace of encroachment contrasts with the increased rate that occurred in the Great Plains prairie.

All the prairies except one had highly negative indices of moisture availability (Table 1). The mean IND was −3.1 across all Pennsylvania limestone prairies. The moisture availability index was −3.5 (very xeric) for the Great Plains prairie and −3.9 (very xeric) for the Westfall Ridge prairie.

Several types of anthropogenic disturbance and management influences were identified in the 10 xeric limestone prairies of Pennsylvania (Table 1). First, though not detected directly at the sites, fire suppression has been a strongly enforced policy since the beginning of the 20th century throughout all of Pennsylvania (Abrams and Nowacki 1992). Second, agricultural activities, such as plowing and livestock grazing, were common disturbances surrounding seven limestone prairies. Third, limestone quarries were present very near five limestone prairies. Fourth, forest clearing by utility providers for powerline right-of-ways occurred within four limestone prairies.

A total of 99 species was detected in the Great Plains prairie remnant (Table 2), 25 of which were exotic (25%). Eleven species identified by PNDI botanists were not detected in the present survey, including *Aster ericoides, Trichostema brachiatum, Andropogon gerardii, Schizachyrium scoparium, Sporobolus asper*, and *Elymus trachycaulus*. A total of 78 species was detected in the Westfall Ridge prairie, 22 of which were exotic (28%). Four species identified by PNDI botanists were not detected in the present survey, including *Calystegia spithamaea, Desmodium rotundifolium,* and *Scuttelaria elliptica*.

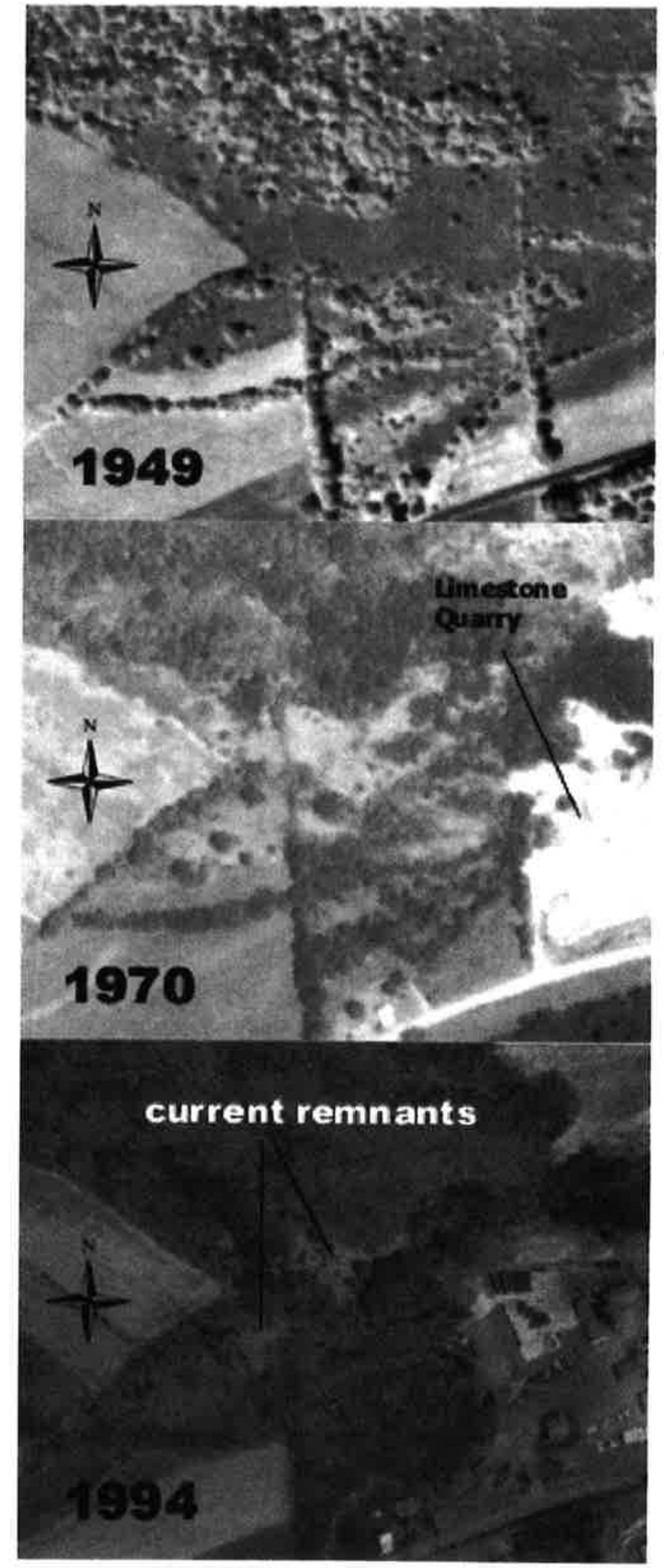

FIGURE 4. Woody plant invasion in the Westfall Ridge Prairie, Juniata County, in central Pennsylvania from 1949 to 1994. Photos from 1956 and 1987 are not shown. A limestone quarry, indicated in the 1970 photo, began operations in the 1950s. Agriculture is also present to the west of the prairie.

DISCUSSION

Woody plant invasion

Both limestone prairies in this study experienced invasion by woody species from 1949 to 1994 (Figure 3), and recent field work in 2001 confirmed that woody plants have continued to invade since 1994. Other studies using repeat aerial photographs have demonstrated areal decline in size of limestone prairies due to woody plant invasion in southern Ohio (Annala et al. 1983, Annala and Kaputska 1983), Indiana (Aldrich et al. 1982, Bacone et al. 1983), and the Missouri Ozarks (Kimmel and Probasco 1980, Lowell and Astroth 1989, Ver Hoef et al. 1993). This study confirms that woody plant encroachment is a serious problem for xeric limestone prairies in Pennsylvania as well.

The increased rate of woody plant encroachment in the late 1980s in the Great Plains prairie likely was caused by a change in land use. The landownership shifted over 20 years ago, and the previous owner grazed cattle on the site, which may have suppressed some woody plant growth (Ritchie et al. 1998). The invasion rate increased when the current owner stopped grazing the land. If the average trend continues, the Great Plains prairie could be converted to shrub fields or woodland by the year 2007. However, complete eradication of the small prairie community is unlikely since the rocky Opequon soils (Braker 1981) will prevent woody plants from establishing on the extremely shallow sites (Kucera and Martin 1957, Ware 2002).

The decreased rate of woody plant invasion after 1970 in the Westfall Ridge prairie is most likely due to the extremely rocky soil in the last two remaining patches of prairie on the site (Figure 3). Soil in the surrounding forest, which was prairie earlier in the century, appeared less rocky than in the remaining prairie area (Laughlin, D.C., pers. obs.). Kucera and Martin (1957) observed that forest soil surrounding limestone prairies was much deeper (> 120 cm) than prairie soils (mean = 12.2 cm). Soils in the Westfall Ridge prairie belong to the Elliber and Opequon soil series, which are two of the most rocky, well-drained soils in central Pennsylvania (Lipscomb and Farley 1981). The extremely xeric soil impedes rapid woody encroachment, and without prescribed fire, it may allow the prairies to persist indefinitely.

The Importance of Disturbance in Xeric Limestone Prairies

There is an interesting interaction between endogenous (e.g., edaphic conditions) and exogenous (e.g., human disturbances) factors in the maintenance of xeric limestone prairie structure. Extreme edaphic conditions preclude the complete eradication of limestone prairies by woody plant invasion. In Pennsylvania, woody plant encroachment may cause conversion of limestone prairies to a more barren-like habitat (shrubby, open forests with grass-dominated understories; sensu Hutchison 1994), but complete conversion to hardwood forest is extremely unlikely. Highly xeric, shallow and rocky soils (Table 1) and periodic droughts often cause woody plant mortality via desiccation in limestone prairies (Bartgis 1993). Periodic droughts constitute one of the two major forms of disturbance in grasslands (van Andel et al. 1987) since they change the condition of xeric prairie soil from dry to extremely dry. In the Ozarks, soil erosion exceeds weathering of bedrock due primarily to the steepness of the slopes; this maintains droughty soil conditions for long periods of time (Ware 2002). However, extreme edaphic conditions can only prevent woody plant invasion on the most shallow and rocky sites within the prairies. Although some limestone prairies (or portions of them) may be able to maintain the open grass-dominated structure without disturbance (see Table 2, Baskin et al. 1994), the majority of limestone prairies are dependent on disturbances (Baskin and Baskin 2000).

Non-human disturbances, such as native ungulate browsing, historically could have played a role in preventing woody plant encroachment in limestone prairies. Browsing is a form of disturbance within the category of defoliation regimes (van Andel et al. 1987). Woody species tend to respond negatively to browsing pressure (DeSelm 1989, Ritchie et al. 1998, van Langevelde et al. 2003). Elk and small populations of bison inhabited central Pennsylvania prior to Euro-American settlement, but they are currently extirpated from their presettlement ranges (Murie 1951, Roe 1970, Mitchell 1982, Thomas and Toweill 1982, Belue 1996). Colonel Kelly described Buffalo Valley (near Lewisburg, Pennsylvania) as "wooded originally with large but scattered trees, so that the grass grew abundantly and furnished good pasturage for the buffalo, and that the animal had been from this circumstance very abundant in the valley" (Allen 1876). Bison, however, are primarily grazers and tend to avoid eating woody plants (Holechek et al. 2001). The only way to positively identify the influence of browsing ungulates in limestone prairies is to conduct experimental research. It seems more likely that anthropogenic disturbances had a greater impact on prairie-forest dynamics than native ungulates.

Several anthropogenic disturbances have influenced the 10 known limestone prairies in Pennsylvania (Table 1). Anthropogenic disturbances, such as Indian-set fires, forest clearing, and soil erosion associated with agricultural activities (J.M. Baskin and C.C. Baskin, pers. comm.) have been implicated in disrupting the tendency toward woody encroachment in other limestone prairies (Baskin et al. 1994, Baskin and Baskin 2000). Some of these disturbances were common in central Pennsylvania. Not only were most of the forests in Pennsylvania cleared by logging interests by ca. 1900, but central Pennsylvania also has a rich agricultural heritage in the fertile limestone valleys of the Ridge and Valley (Cuff et al. 1989). In the following discussion, I explore the likelihood of Indian-set fires as an anthropogenic disturbance in Pennsylvania and the current influence of human disturbances on limestone prairie structure.

Fire

The Great Plains in central Pennsylvania were described as "large open plains, cleared either by Indians or accidental fire" (Albion and Dodson 1934). How accidental were these fires? Fire is a key disturbance agent in most grassland systems. Fire has been implicated as a major disturbance agent in other floristically similar prairies, glades, and barrens in Ohio (Annala et al. 1983, Annala and Kaputska 1983), West Virginia (Bartgis 1993), southwestern Virginia, northwest Georgia, northeast Alabama, East Tennessee (DeSelm et al. 1969, DeSelm 1989, 1990, 1993, 1994), northwest Alabama (Webb et al. 1997), Kentucky (McInteer 1946), Missouri (Beilmann and Brenner 1951, Kucera and Martin 1957, Kimmel and Probasco 1981, Lowell and Astroth 1989, Ware 2002), and Indiana (Wade and Menges 1987).

Anthropogenic fire use has significant impacts on landscapes containing prairies and barrens (Guyette et al. 2002, 2003). Fire histories recorded in fire scars have consistently demonstrated that fires were most frequent during Native American occupation (Guyette and McGinnes 1982, Guyette and Cutter 1991, Cutter and Guyette 1994) and that fires were much less common during the past century (Robertson and Heikens 1994). Batek et al. (1999) determined that anthropogenic fire regimes played an important role in the development of vegetation mosaics in the Ozarks, a region where xeric limestone prairies are common (Baskin and Baskin 2000). Presettlement fire intervals were determined to be 3.2 years in a limestone prairie in the Ozarks (Guyette and McGinnes 1982), 4.3 years in the Caney Mountain Wildlife Refuge in the Ozarks (Guyette and Cutter 1991), and 2.8 years on an oak-hickory ridgetop in the Ozarks (Cutter and Guyette 1994). Fire frequencies decreased when Native Americans left the region and increased again upon arrival of the settlers. Similar fire histories are likely in other oak forests (Abrams 1992). Fire histories have not been determined in eastern limestone prairies, but fire scarred trees have been noted in West Virginia limestone prairies and barrens (Bartgis 1993), and several charred tree stumps were seen in Ohio limestone prairies (Annala and Kaputska 1983). Fire likely played a role in maintaining the open, perennial grass-dominated structure of limestone prairies in Pennsylvania as well. The build up of fine fuels and the xeric quality of the site together create an environment that is prone to burning (Pyne et al. 1996).

The historic fire frequencies for central Pennsylvania are largely unknown because evidence of fire rapidly disappears in the humid climate and undisturbed natural lake sediments are difficult to locate for pollen and charcoal analyses. Historical evidence of fire in the Northeastern United States is controversial, and Russell (1983) proposed that Indian-set fires were restricted to areas immediately surrounding Indian settlements. Although direct evidence of fire in Pennsylvania is not abundant, accumulated ecological evidence suggests that fire played a key role in Pennsylvania oak forests (Bromley 1935, Day 1953, Buell et al. 1954, Marquis 1975, Lorimer 1985, Whitney 1990, Abrams 1992, Abrams and Nowacki 1992, Ruffner and Abrams 2002).

Lightning-set fires are limited in Pennsylvania (Haines et al. 1978). Only 2% of the fires in Pennsylvania are ignited by lightning according to Pyne (1982). This is not because lightning is infrequent, but because actual ignitions tend to be extinguished by the accompanying precipitation during thunderstorms (Ruffner and Abrams 1998). However, "eyewitness accounts and charcoal studies suggest that Indians were responsible for increasing fire frequency above the low numbers that would have been caused by lightning" in Pennsylvania (Abrams 1992). This was also the case in the Ozarkian highlands (Guyette et al. 2002). Other non-human ignition sources in Pennsylvania include charcoaling in the iron industry and sparks from railroads (Haines et al. 1978). An old railroad bed is within 50 m of the Great Plains remnant. Sparks from trains may have ignited fires (Haines et al. 1978) within the historic Great Plains area, but these ignitions were likely localized and infrequent.

Native Americans burned their woodlands for a number of reasons, mostly those related to hunting practices (Van der Donck 1841 cited in Russell 1983). Burning the forest understory kept it free from dense brush, dried plant material, and dead branches. This made traveling easier and quieter for the hunter. Some tribes burned their forests to stimulate berry production (Vora 1993). The Delaware Indians were prominent in Pennsylvania prior to European settlement, and they were reported to have set fires in large circles to trap all the game within the enclosing ring of flame (Lindestrom 1925). Indian-set fires were reported in Franklin County (the location of Baker Caverns prairie [Figure 1]), where "the woods and grass of the mountains and prairies were burned and their game was driven from concealment" (Richard 1887 cited in Klotz and Walck 1993). Frequent disturbances, interpreted to represent native burning cycles, were also characteristic of an Iroquoian forest settlement in northwestern Pennsylvania (Ruffner and Abrams 2002).

Relying solely on historical documents, Russell (1983) claims that most Indian-set fires were restricted to sites of Indian habitation. However, the limestone prairies documented in this study were not located near historic Indian settlements (Wallace 1965, Sluyter, A., The Pennsylvania State University, pers. comm.). Instead, they were located near Indian trails (Wallace 1965). The Great Plains prairie remnant in Penns Valley, Centre County, lies very near a famous Indian trail crossroad known as The Forks (Macneal 1998, Laughlin 2002); the Westfall Ridge prairie and other nearby prairies in Juniata County are very close to the Tuscarora Path; the Georgetown Road passed through Williamson, Pennsylvania, which is close to Baker Caverns prairie; and Penns Creek Path crossed through the historic "plains" of Centre County (Wallace 1965). If historical Indian-set fires did maintain xeric limestone prairies and oak woodlands, then Indian-set fires were not merely restricted to Indian settlements; they also were common along trails.

Regardless of who or what ignited the fires, wildfires have been heavily suppressed in Pennsylvania since the early 1900's (Haines et al. 1978). According to data compiled by the Pennsylvania Bureau of Forestry, Abrams and Nowacki (1992) calculated that "the amount of area burned per year and the average fire size in all of Pennsylvania decreased by 99% and 98%, respectively, between 1908 and 1989," and "it is probable that early fire records were incomplete and underestimated by 50% or more." Consequently, it is likely that limestone prairies in Pennsylvania have not burned for over a century (Table 1).

Other Anthropogenic Disturbances

Historically, human-set fires may have maintained the grass-dominated structure of limestone prairies, but more recent anthropogenic disturbances have significantly influenced the limestone prairies in Pennsylvania (Table 1). Agricultural activities, forest clearing by logging industries and utility providers, and quarrying activities opened up areas for colonization by prairie species.

Agricultural activities, such as plowing and grazing, are very common endeavors in the valleys of central Pennsylvania (Cuff et al. 1989). Aerial photographs show that both prairies in this study were very near crop fields (Figures 2 and 4). Settlement agriculture (late-1700s to mid-1800s) was the first threat to the limestone prairies of Pennsylvania. The historical boundary of the Great Plains, elucidated by Losensky (1961) and Macneal (1998), indicates that the prairie persisted on areas of deeper soil, which have since been converted to cropland. Evidence from floristic composition suggests that a slightly more mesic component was present in the flora. *Andropogon gerardii* and *Sorghastrum nutans* were detected by Kunsman (1990), but only a couple individuals of *Sorghastrum* were found recently, and *Andropogon* was not seen at all. Mesic prairie species once may have been more important in areas within the Great Plains where soils were deeper.

Fortunately, not everything was plowed under. I do not believe that the prairie remnants in this study were ever tilled because the soils are too shallow (see Harper 1920). However, soil erosion associated with livestock grazing may have played a role in removing soil from the upper surface layers, thereby creating more xeric conditions in the soil, which are best exploited by xeric prairie species. Grazing pressure may have also played a role in maintaining limestone prairies. Livestock grazed in the Great Plains prairie for many decades (Table 1). As suggested above, removal of grazing pressure after 1970 may be responsible for the increased rate of woody plant invasion in the Great Plains prairie. Grazing was likely a factor in maintaining other limestone prairies (Table 1; see also DeSelm 1993), though detailed grazing histories for the study areas were not compiled in this study.

Limestone quarries were found near five limestone prairies (Table 1). In fact, a limestone quarry can be seen appearing in the 1950s aerial photograph immediately east of the current Westfall Ridge Prairie Preserve (Figure 4). Whether or how the quarrying activities actually influenced the vegetation is uncertain. Quarries may exist only near the prairies because the limestone bedrock is so near the surface. However, it appears that historical limestone quarrying may be responsible for creation of a limestone prairie in Canoe Creek State Park, Pennsylvania, since many limestone prairie species thrive on the exposed bedrock (Kunsman 1988). DeSelm (1993) noted that three "barrens and glades" in the southern Ridge and Valley were found near limestone quarries. Currently, however, quarries are undoubtedly more of a threat than a positive influence to the rare limestone prairies. Limestone quarries threaten limestone prairies in West Virginia (Bartgis 1985) and one quarry destroyed a species rich prairie/barren complex on Knobly Mountain, West Virginia in 1991 (Bartgis 1993).

Forest was cleared for powerline right-of-ways (ROW) on four limestone prairies in Pennsylvania (Table 1). In no case is the prairie vegetation strictly limited to the cleared path for the powerline. However, clearing woody vegetation to maintain the ROWs is apparently beneficial for the prairie species that thrive in high light conditions. These are examples of the positive role that forest clearing can play for the persistence of rare non-forest species. DeSelm (1989, 1993) noted that barrens in Tennessee were found often along mown roadsides or under powerline ROWs maintained by bushhogging. Mowing, or some other mode of woody plant removal, will be necessary to maintain open prairies (Baskin, C.C., pers. comm.). For example, in the Westfall Ridge Prairie, The Nature Conservancy felled several *Juniperus virginiana* trees and removed them from the site by hand (the eastern red-cedars can be seen in Figure 4 in the middle of the largest remnant, but they are no longer in the preserve).

Management Implications

Aerial photographs demonstrate how quickly these prairies have been and are being replaced by woody species. Although some xeric limestone prairies may be able to maintain their grass-dominated structure due to the highly xeric nature of the soils, most limestone prairies will be converted to barrens (sensu Hutchison 1994) or woodlands without the periodic disturbances that impede the encroaching woody flora (Bartgis 1993, Baskin and Baskin 2000). Soil conditions may slow the rate of woody plant invasion (DeSelm 1994), but if these limestone prairies are not managed, they and their associated rare plant species will be in danger of extirpation in Pennsylvania.

It is now widely accepted that conservation and restoration decisions "must consider the role of disturbance" (Pickett and White 1985) in order to be successful. One of the central questions in limestone prairie disturbance ecology is how often must prairies be disturbed for optimal maintenance? Frequent fire regimes near limestone prairies in the Ozarks suggest that historical fire frequencies could also be high for other limestone prairies in North America. However, fire histories have not been determined for limestone prairies in the Eastern United States. Baskin et al. (1994) stated that xeric limestone prairies must be "occasionally" disturbed. Wade and Menges (1987) concluded that burning was important in limestone prairies in Indiana but the optimal frequency of burns was not known. Not only is the frequency of disturbance unknown, but the intensity of disturbance also is not well understood. DeSelm (1989) concluded that very intense disturbances (i.e., intense grazing history and frequent mowing) decreased species richness. Therefore, if fire or other management techniques are used too often they may negatively impact plant diversity. Land managers in Pennsylvania would greatly benefit from quantitative dendrochronological studies to determine historical frequency of fires near limestone prairies so that "optimal" disturbance frequencies can be accurately emulated.

Management practices for limestone prairies in Pennsylvania will be similar to restoration techniques in the tallgrass prairies. Mechanical thinning of trees and shrubs accompanied by prescribed burns likely will maintain the integrity of these prairies into the future.

Tree removal from the surrounding forest alone will not stimulate prairie seedling recruitment from the residual seed bank, so introducing native seeds or seedlings into the thinned areas will be necessary for increased success of native herbaceous plant production (Laughlin 2003). Moreover, exotic plant removal may be necessary where exotics outcompete members of the native flora. For example, The Nature Conservancy manually removes the exotic invasive *Centaurea maculosa* almost annually since it is so abundant in the Westfall Ridge prairie. Nearly a quarter of the species in each prairie in this study are exotic (Table 2). Removal of introduced weeds might become increasingly important if exotic plants negatively impact native populations, especially populations of species listed as threatened in Pennsylvania.

This study emphasizes the need for exogenous disturbances and human management in xeric limestone prairies. Although management options in limestone prairies must be researched further, designing robust, well-replicated experiments of restoration treatments may be impossible in limestone prairies since they are too small and too few (Laughlin and Uhl, in press) for adequate experimentation. Regardless, implementation of small-scale treatments, like the thinning project conducted by The Nature Conservancy, is of paramount importance if land managers wish to restore or maintain limestone prairies in Pennsylvania. Historically, xeric limestone prairies were maintained by anthropogenic disturbances; therefore, human intervention will be necessary to save these prairies from woody plant encroachment.

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EFFECTS OF THREE SEWAGE TREATMENT PLANTS ON WATER CHEMISTRY OF THE LACKAWANNA RIVER (LACKAWANNA COUNTY, PENNSYLVANIA)[1]

DAVID H. BYMAN,[2] DANIEL S. TOWNSEND,[3] JOSEPH C. CALABRO,[3] RAYMOND M. CIAMPICHINI,[2] MICHELE GRIGUTS,[2] JEANNE NEUREUTER,[2] ALAN R. PRATT,[2] GRETCHEN SPOTT[2]

[2]*Penn State Worthington Scranton*
120 Ridge View Drive
Dunmore, PA 18512

[3]*Department of Biology*
University of Scranton
Scranton, PA 18510

ABSTRACT

Mineral and heavy metal levels at three sewage treatment plants (STPs) on the Lackawanna River, a major tributary of the Susquehanna River in northeastern Pennsylvania, were studied in 1990-91. Specific conductance, total alkalinity, hardness, copper, iron, manganese, and zinc levels were measured above and below STPs at Archbald, Throop and Scranton, located 37.8 km, 24.2 km, and 12.6 km, respectively, upstream of the confluence with the Suquehanna River. Specific conductance was significantly increased at all three STPs, with Archbald causing the largest increase. Total alkalinity levels were low overall, and not affected by any of the three STPs. Total hardness levels, and concentrations of iron, manganese, and zinc were all significantly increased by the Archbald STP, while the Throop STP caused significant increases in total hardness and manganese. Copper concentrations were unaffected by any of the plants. The three STPs that were studied had small effects on mineral and heavy metal contamination of the Lackawanna River; they have likely been minor contributors to pollution of the Susquehanna River in comparison to the effects of large-volume mine drainage outfalls near the mouth of the Lackawanna River.
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INTRODUCTION

The Lackawanna River is a major tributary of the North Branch of the Susquehanna River in northeastern Pennsylvania that arises as two branches in southeastern Susquehanna County and western Wayne County and flows through Lackawanna County into northeastern Luzerne County where it joins the Susquehanna River (McMorran, 1989). The Lackawanna River drains an area of 901 km^2 containing urban, suburban and rural areas. The largely urbanized river valley lies within the northern anthracite coalfield, where extensive coal mining went on from the 1880s through the 1950s. Large culm piles, old coal processing sites and other spoil areas of past coal mining are common sights, many close to the river. Numerous outfalls from water-filled deep mines occur along most of the 64 km main stem of the river (McMorran, 1989). Other point sources with the potential to affect water quality include sewage treatment plant (STP) outfalls (Kupsky, 1981, Kupsky and Wills, 1991).

The Lackawanna River receives treated sewage discharge from six major sewage treatment plants (STPs).

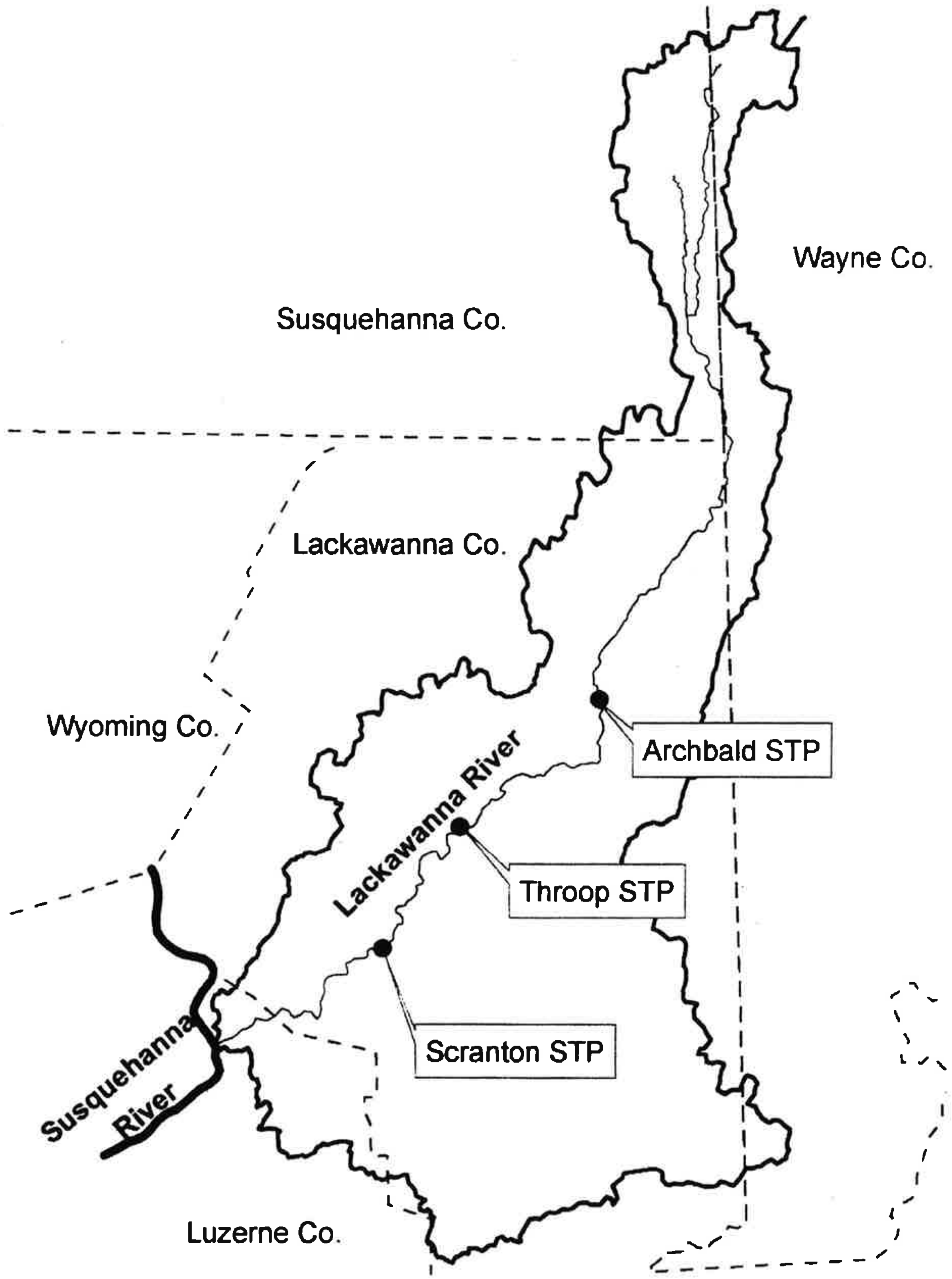

FIGURE 1. The Lackawanna River in northeastern Pennsylvania, indicating locations of the Archbald, Throop and Scranton sewage treatment plants, the river's drainage area (bold line) and county lines (dashed lines).

TABLE 1. Mean conductivities, alkalinities, calcium hardness and total hardness levels, and concentrations of iron, manganese, zinc and copper above and below three sewage treatment plants on the Lackawanna River during 1990-91; n = number of paired samples

	Archbald			Throop			Scranton		
	Above	Below	n	Above	Below	n	Above	Below	n
Conductivity (μmhos/cm)	123.5	180.9**	37	137.2	145.0**	27	188.2	208.4**	79
Alkalinity (mg/L as $CaCO_3$)	19.2	19.9	37	15.5	15.6	26	21.7	22.1	36
Calcium hardness (mg/L as $CaCO_3$)	38.2	46.1**	37	41.7	42.0	26	47.6	47.2	37
Total hardness (mg/L as $CaCO_3$)	74.2	99.5**	37	82.6	87.0*	26	87.8	88.1	37
Iron (mg/L)	0.164	0.247**	9	0.242	0.297	9	0.254	0.287	9
Manganese (mg/L)	0.079	0.153**	9	0.166	0.184*	9	0.141	0.142	9
Zinc (mg/L)	0.021	0.026*	23	0.027	0.026	12	0.030	0.031	23
Copper (mg/L)	0.019	0.020	9	0.021	0.021	9	0.021	0.020	9

*Means above and below are different by paired samples t-test, $p < 0.05$
**Means above and below are different by paired samples t-test, $p < 0.01$

In 1990-91, the effects of three of those STPs were studied; temperature, pH, dissolved oxygen, ammonia nitrogen, nitrate nitrogen, and phosphate were reported previously (Byman et al., 1999). Here, the results concerning the effects of the same three STPs on conductivity, alkalinity, hardness, and heavy metals in the river are reported.

STUDY SITES

Three STPs (Scranton, Throop and Archbald) located in Lackawanna County on the main stem of the Lackawanna River were studied (Figure 1). Between the downstream Scranton STP and the upstream Archbald plant, the river flows over a substrate of cobblestone and glacial till and occasionally the bare bedrock of Llewelyn sandstone containing iron and manganese. The Scranton STP (41° 23' 219" N, 75° 41' 28" W), located 12.6 km upstream of the Lackawanna's confluence with the Susquehanna River, had a capacity of 28 million gallons per day (mgd) at the time of this study, the largest STP on the Lackawanna River. The Throop STP (41° 27' 01" N, 75° 38' 02" W), located 24.2 km upstream, had a capacity of 7.0 mgd. The Scranton and Throop STPs are on a section of the river classified as a Warm Water Fishery (Pennsylvania Department of Environmental Resources [PADER], 1992), a section that Copeland and Moase (1992) found to be polluted and recommended against active management for fisheries. The Archbald STP (41° 29' 24" N, 75° 32' 41" W), located 37.8 km upstream with a capacity of 5.0 mgd, is on a section of the river classified as a High Quality Coldwater Fishery and recommended for management as Class A wild brown trout water (Copeland and Moase, 1992). All three plants provided secondary treatment with nitrification, and the treatment process was activated sludge. The Lackawanna River is a fifth order stream at all of our study sites (Strahler, 1951).

MATERIALS AND METHODS

We chose sample sites at least 100 m upstream and downstream of the discharge pipe of each STP. Sample sites were chosen to preclude the occurrence of any other point discharges or surface inflows between upstream and downstream sites and to allow adequate mixing of effluent with river water downstream. Sampling was conducted weekly in the morning. Samples were collected in glass bottles, capped underwater to eliminate air bubbles, and returned immediately to the laboratory for analysis. Comparison of river water temperatures and those of samples tested in the laboratory indicated negligible temperature changes between collection and testing. Laboratory measurements of con-

TABLE 2. Comparison of the upstream-downstream changes in chemical variables among the three STPs on the Lackawanna River. Mean values with different superscript letters were significantly different in multiple comparisons tests ($p < 0.05$).

	Mean changes at each site					
Variable	Archbald	Throop	Scranton	F	df_{error}	p
Conductivity (μmhos/cm)	57.5[a]	7.8[b]	20.3[b]	31.2	140	< 0.001
Calcium hardness (mg/L)	7.92[a]	0.38[b]	−0.35[b]	30.1	97	< 0.001
Total hardness (mg/L)	25.35[a]	4.38[b]	0.27[b]	19.8	97	< 0.001
Manganese (mg/L)	0.074[a]	0.019[b]	0.001[b]	31.0	24	< 0.001
Iron (mg/L)	0.74	0.49	0.29	0.4	24	0.675
Zinc (mg/L)	0.005	−0.001	0.001	0.7	55	0.521

ductivity, alkalinity, calcium and total hardness, concentrations of copper (mg/l), iron (mg/l), manganese (mg/l), and zinc (mg/l) were made according to Clesceri et al. (1989).

Up to 79 samples were collected at Scranton between January 1990 and August 1991, 56 samples between February 1990 and May 1991, and 38 samples at Archbald between October 1990 and August 1991. Some analyses were not performed every week as our undergraduate student sample collectors were not always available, resulting in smaller sample sizes for some variables.

None of the variables exhibited deviations from normality and there was no significant heteroscedasticity among samples; hence parametric tests were used in all comparisons. Differences between upstream and downstream samples at each site were tested using paired two-tailed t-tests. Differences among the three STPs in the magnitude of upstream-downstream changes were tested using One Way ANOVA, followed by multiple comparisons tests (Tukey's HSD test) when ANOVAs were significant. An $\alpha = 0.05$ was used for all statistical tests (Sokal and Rohlf, 1995).

RESULTS

Significant downstream increases in conductivity (specific conductance) were found at all three STPs, with the largest at the Archbald plant (Tables 1, 2). Significant downstream increases at the Archbald plant also included calcium hardness, total hardness, iron, manganese, and zinc (Table 1). The Throop STP caused smaller, but significant, downstream increases in total hardness and manganese (Table 1). Except for conductivity (specific conductance), no significant downstream increases in any chemical variable occurred at the Scranton STP (Table 1). Neither alkalinity nor copper concentrations were affected by any STP (Table 1).

Upstream to downstream changes in chemical variables were significantly different among the three STPs for conductivity (specific conductance), calcium hardness, total hardness and manganese, with the Archbald plant exhibiting the greatest increases in all four variables (Table 2). While changes in iron and zinc concentrations wre also greatest at the Archbald plant, they were not significantly different from those at Throop or Scranton (Table 2).

DISCUSSION

Conductivity (specific conductance) was the only variable that exhibited significant increases at all three STPs, although the Archbald plant caused a significantly larger increase than the other two plants (Table 1, 2). Measured as the capacity of an aqueous solution to carry an electric current, specific conductance provides a relative measure of total dissolved minerals and metals in the water (Greenberg et al., 1992), and hence the effectiveness of an STP in removing them from wastewater. Our results suggest that none of the STPs are completely effective in this regard. Total hardness (a measure mainly of Ca^{2+} and Mg^{2+} levels), iron, manganese and zinc levels all increased significantly at the Archbald plant, while hardness and manganese increased significantly at the Throop plant (Table 1). River water hardness was within the moderately hard range (75-150 mg/L as $CaCO_3$) at all three sites (USEPA, 1986).

In contrast to conductivity, total alkalinity did not change significantly at any STP (Table 1). Total alkalinity measures the buffering capacity of water, mainly a result of bicarbonate, carbonate, phosphate and hydroxide ion concentrations (Greenberg et al., 1992, USEPA, 1986). In fact, total alkalinity levels in the river at all three sample sites were near the EPA's minimum criterion for freshwater aquatic life of 20 mg/L (USEPA, 1986), a result consistent with results of other studies of the Lackawanna River (McMorran, 1989; Copeland and Moase, 1992). The low total alkalinities may reflect the effect of significant buffering activity of acid mine outfalls that occur along the river's length (McMorran, 1989).

The Archbald STP had the greatest effect on the river of the three plants (Tables 1, 2). Archbald's substantial contribution to declines in water quality is likely a consequence of its more upstream location, where the river is somewhat smaller and quality of the receiving water is higher than at the other two plants (Copeland and Moase, 1992). Increases in specific conductance, hardness, iron manganese and zinc levels over background at the Archbald plant were either maintained or exacerbated by the other outfalls. This pattern is consistent with some water quality parameters, including dissolved oxygen and pH, reported in Byman et al. (1999), although nitrates and phosphates exhibited the opposite trend, with greater increases at the Throop and Scranton STPs than at Archbald. However, as the only STP on the portion of the river classified as a High Quality Coldwater Fishery (Copeland and Moase, 1992), the Archbald STP may have serious consequences for aquatic biota in its portion of the river.

The three STPs we studied had a small effect (at Archbald) or no effect (Throop and Scranton) on levels of zinc and copper. We found that ambient concentrations of both heavy metals were equivalent to or below threshold chronic levels for many freshwater invertebrates and vertebrates (Kiffney and Clements, 1994; Kucken et al., 1994; USEPA, 1986), although copper concentrations were above chronic levels for brook trout (USEPA, 1986). While the Archbald STP increased iron levels, and both Archbald and Throop plants increased manganese concentrations, those increases were small compared to large contributions from mine outfalls along the Lackawanna River that have been reported previously (McMorran, 1989).

The Lackawanna River is a major tributary of the North Branch of the Susquehanna River. Brush et al. (1979) reported large increases in metal concentrations in the section of the Susquehanna River that receives the Lackawanna River. To the extent that the Lackawanna contributes to those increases, they are likely to be mainly a consequence of substantial loading from two major mine outfalls at Old Forge and Duryea in the last 5 km above the confluence (McMorran, 1989). The results indicate that the three STPs we studied had small, albeit measureable, effects on water quality of the Lackawanna River, and are likely to be minor sources of mineral and heavy metal pollution contributed to the Susquehanna River.

ACKNOWLEDGMENTS

The undergraduate students who participated in this study were supported by a grant from the Chesapeake Bay Foundation. We would like to thank Arthur Popp of the Lackawanna River Corridor Association, Scranton, PA for preparation of the map of the Lackawanna River used in Figure 1.

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USE OF INTEGRATED LEARNING MODULES TO TEACH ENGINEERING TECHNOLOGY STUDENTS[1]

SOHAIL ANWAR AND SHAMSA S. ANWAR

Penn State University,
Altoona College,
Altoona, PA 16601

ABSTRACT

This paper describes a project that was recently conducted at Penn State University, Altoona College (Penn State Altoona). The project consisted of the use of integrated learning modules developed by the authors of this paper. The modules integrate various concepts from mathematics, physics, and engineering technology to provide students with a clear understanding of the usefulness of mathematics and physics in real-world engineering problems. It is expected that by teaching students how the disciplines of mathematics, physics, and engineering technology are interconnected, they will be better prepared to deal with cross-disciplinary problems. These modules are suitable for use in a one-semester mathematics course for associate degree engineering technology students. The paper also presents the findings of a survey conducted to assess the effectiveness of the learning modules.
[J PA Acad Sci 78(1): 34–37, 2004]

INTRODUCTION

In most of the engineering technology programs offered by the educational institutions in the United States, the disciplines of mathematics, physics, and engineering technology are studied separately. Engineering technology students are seldom shown how these disciplines are interconnected. Engineering technology students usually study mathematics and physics courses with the perception that these courses are a "necessary evil". As a result of this perception, many students who may have good technical skills sometimes do not exhibit good performance in mathematics and physics.

As our society becomes increasingly technology oriented, we depend even more on a solid educational foundation in science, mathematics, and engineering (Robinson et al. 2003). Therefore, if an effort is made to teach students how the disciplines of mathematics, physics, and engineering are interconnected and how the concepts of one discipline are applied to the other, it is likely that students will be greatly motivated to study mathematics and physics. Integrating mathematics, science, and engineering courses is an effective means of teaching students to deal successfully with cross-disciplinary problems (Loulache et al. 2001).

There exists a significant amount of literature describing the efforts that have been made at numerous educational institutions to integrate mathematics, science, and engineering/engineering technology courses. The evolution of an integrated first-year curriculum at Rose-Hulman Institute of Technology is reported by Froyd and Rogers (1997). The year-long curriculum integrates topics in calculus, physics, chemistry and engineering. Gaonkar and Abaté (2002) describe the design and implementation of an interdisciplinary program that integrates electronics, mathematics, reading/writing, and computing skills. This program known as the Integrated Interdisciplinary Program (IIP) has had a dramatic positive impact on retention rate for two-year engineering technology students at Onondaga Community College, Syracuse, NY. Segal and Townsend (2002) describe an integrated mathematics-writing curriculum offered by the Ward College of Technology at the University of Hartford. Through this curriculum, mathematics and English are taught not as separate courses but as two grammars that must be used to formulate solutions to problems from the six engineering technology disciplines pursued at Ward College of Technology. Additional examples of integrated courses and curricula are described by Pines et al. (2002), Kowalczyk et al. (1999), and Morgan et al. (1998).

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STATEMENT OF PROBLEM

In the two-year associate degree electrical and mechanical engineering technology programs at Penn State Altoona, the disciplines of physics, mathematics, and engineering technology are studied separately. Rarely an effort is made to show the engineering technology students how these disciplines are connected together.

Another problem is the lack of instruction regarding the real-life applications of mathematical and physical concepts. As a result of this deficiency in the physics and mathematics courses offered by Penn State Altoona, when the students take engineering technology courses, they are not adequately prepared to apply physical and mathematical concepts to solve real-life engineering application problems.

DEVELOPMENT OF INTEGRATED LEARNING MODULES

In order to develop students' ability to effectively make use of mathematics and physics in solving engineering technology problems, integrated learning modules were developed during the academic year 2001-2002 by the authors of this paper. These modules are based on selected concepts of mathematics, physics, and engineering technology presented in an integrated fashion. These concepts include complex numbers, logarithmic and exponential equations, RL and RC time constants, magnetism, and fundamentals of AC circuit analysis. The integrated modules developed around these concepts are suitable for use in a one-semester course in mathematics for associate degree engineering technology students at Penn State Altoona.

A total of four integrated learning modules have been developed. They are titled as follows:

1. Complex Numbers.
2. Exponential and Logarithmic Functions.
3. AC Circuits
4. RL and RC Time Constants.

Each module begins with the description of a real-life industrial situation. These situations are based on case studies conducted by the authors of this paper. As an example, the real-life industrial situation for the learning module "Exponential and Logarithmic Functions" is described as:

The ACME BioTech Company is a bio-medical start-up company that produces a radioactive tracer fluid for use in the discovery and treatment of thyroid disease. ACME BioTech employs fifteen people: four professionals; six technicians; and five general staff employees. The annual sales of the company amount to approximately nine million dollars. In the BioTech production facility, the radioactive tracer fluid must be delivered from one place in the facility to another where the loading bay is located, without endangering the company workers. In order to develop appropriate safety measures to protect the workers, the ACME BioTech technical staff will need to measure radiation produced by the radioactive substance used in the tracer fluid. Measurement of radiation requires adequate knowledge of the rate of decay of a radioactive substance based on its half-life. Exponential functions are commonly used in the calculations associated with the rate of decay of a radioactive substance.

In each module, the real-life industrial situation, such as the one described above, is followed by a detailed conceptual background which consists of a detailed explanation of all the mathematical and the physical concepts relevant to the given industrial situation. For example, the conceptual background for the industrial situation described above, consists of a detailed explanation of exponential and logarithmic functions. This explanation is supplemented by numerous examples which illustrate the use of logarithmic and exponential functions to deal with various engineering and scientific problem solving situations such as the one described above. Each module ends with several application-oriented problems to be solved by students. The completion of each learning module requires three class contact hours.

USE OF INTEGRATED LEARNING MODULES

Students enrolled in the associate degree engineering technology programs at Penn State Altoona are required to take a total of ten credit hours of mathematics during four semesters of their studies. These credit hours translate to three mathematics courses titled Technical Mathematics I (Math 81), Technical Mathematics II (Math 82), and Technical Mathematics III (Math 83).

The course titled Technical Mathematics II (Math 82) is a three credit-hour course taken by associate degree engineering technology students in the second semester of their studies at Penn State Altoona. The course description for Math 82 is as follows: *Exponents, radicals, complex numbers, theory of equations, inequalities, half angle and double angle formulas, inverse trigonometric functions, exponential logarithm, conic sections. Prerequisite: MATH 081*

Math 82 provides engineering technology students with the mathematical background needed to solve DC and AC circuit analysis problems. This course also helps students in solving problems related to DC and AC electrical machines. It is for these reasons that the four integrated learning modules described earlier in this

TABLE 1. Questionnaire used to assess integrated learning modules for Math 82

Ratings used are as follows:
1 = strongly disagree
2 = disagree
3 = neutral
4 = agree
5 = strongly agree

The integrated learning modules used in this course:

1. Introduced real world problems into the classroom	1 2 3 4 5
2. Developed problem-solving skills	1 2 3 4 5
3. Connected theory and practice	1 2 3 4 5
4. Improved retention of material	1 2 3 4 5
5. Stimulated my intellectual curiosity	1 2 3 4 5

paper were used in the Math 82 course during Spring 2003 semester at Penn State Altoona.

A survey questionnaire was used at the end of Spring 2003 semester to assess the effectiveness of the integrated learning modules. The survey questionnaire is shown in Table 1. All the Math 82 students responded to the questionnaire. The students' response rate was 100%.

A total of twenty-one Math 82 students filled out the questionnaire. Table 2 shows the number and the percentage of respondents corresponding to each of the rating for the five questionnaire items.

Table 2 shows that a total of 76% of the Math 82 students either agreed or strongly agreed with the statement that the integrated learning modules introduced real world problems into the classroom. About 24% of the students had a neutral response to this statement.

A total of 76% of the Math 82 students either agreed or strongly agreed with the statement that the integrated learning modules helped them develop problem-solving skills. About 19% of the students had a neutral response to this statement and about 5% disagreed.

A total of 76% of the Math 82 students either agreed or strongly agreed with the statement that the integrated learning modules connected theory and practice. About 19% of the students had a neutral responses to this statement and about 5% disagreed.

A total of 57% of the Math 82 students either agreed or strongly agreed with the statement that the integrated learning modules improved retention of material. About 33% of the students had a neutral response to this statement and about 10% disagreed.

A total of 52% of the Math 82 students either agreed or strongly agreed with the statement that the integrated learning modules stimulated their intellectual curiosity. About 24% of the students had a neutral response to this statement. About 24% of the students either disagreed or strongly disagreed with this statement.

TABLE 2. Number and percentage of respondents corresponding to each of the five ratings for Questionnaire items.

Questionnaire Item 1	Ratings				
	1	2	3	4	5
Introduced real world problems into the class	0 (0%)	0 (0%)	5 (24%)	9 (43%)	7 (33%)
Questionnaire Item 2	Ratings				
	1	2	3	4	5
Developed Problem-Solving Skills	0 (0%)	1 (5%)	4 (19%)	12 (57%)	4 (19%)
Questionnaire Item 3	Ratings				
	1	2	3	4	5
Connected theory and practice	0 (0%)	1 (5%)	4 (19%)	12 (57%)	4 (19%)
Questionnaire Item 4	Ratings				
	1	2	3	4	5
Improved retention of material	0 (0%)	2 (10%)	7 (33%)	9 (43%)	3 (14%)
Questionnaire Item 5	Ratings				
	1	2	3	4	5
Stimulated my intellectual curiosity	1 (5%)	4 (19%)	5 (24%)	10 (47%)	1 (5%)

CONCLUSIONS

This paper describes the development and use of the four integrated learning modules which integrate various concepts from engineering technology, physics, and mathematics. The modules teach two-year associate degree engineering technology students how the disciplines of mathematics, physics, and engineering technology are interconnected and how the concepts from one discipline are applied in the other. All the four modules were used in Math 82 which is a required course for all the engineering technology students at Penn State Altoona. Results of the survey, conducted to assess the effectiveness of learning modules, indicate that significant number of students agreed that the learning modules helped them understand the usefulness of mathematics and physics in real-world engineering problems. The fact that there was a lower percentage of students who either agreed or strongly agreed with the questionnaire items 4 and 5 is attributed to the instructional approach used by the Math 82 instructor to teach the course. The course instructor has agreed to using a modified instructional approach for Math 82 when it will be taught during Spring 2004. The new instructional approach will promote active learning by engaging students in higher-order thinking tasks such as analysis, synthesis, and evaluation related to the real-life situations presented in the integrated learning modules developed by the authors of this paper. These modules will continue to be used in Math 82 course at Penn State Altoona. The authors plan to develop additional integrated learning modules which will be used in Math 83, a calculus based mathematics course taught at Penn State Altoona.

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ADDENDUM:

Abstracts inadvertently omitted from Journal of the Pennsylvania Academy of Science Vol. 77, Abstract and Index Issue, 2004

March 26–28, 2004
Radisson Hotel
Monroeville, PA

Evans, Ryan* and **Robert Coxe**, Western PA Conservancy/PA Natural Heritage Program, 209 Fourth Avenue, Pittsburgh, PA 15222. *The Freshwater Mussels (Bivalvia: Unionidae) of the Shenango River: Past and Present.* —The Shenango River historically had one of the most diverse mussel communities in the state of Pennsylvania. It historically contained 24 species of mussels, but due to numerous impacts in the 20th century, the fauna is currently represented by 13 species. This talk will discuss the state of the mussel fauna of the Shenango River throughout the 20th century and also present the results of recent survey work conducted in 2001 and 2002. Unless management activities focus on protecting and restoring the Shenango, more species will likely be lost in the near future.

Fromert, Gary* and **Jane E. Huffman**, Department of Biology, East Stroudsburg University, East Stroudsburg, PA 18301. *Evaluation of Biolog Phenotype MicroArrays*^{TM} *for the Discriminant Analysis of Escherichia coli in Differentiating Human and Nonhuman Sources of Fecal Pollution.* — Many mehtods for source determination of fecal pollution in water resources are being used to profile subtypes of *Escherichia coli*. It is critical for managing water resources to make accurate identification and assessment of sources of fecal contamination. To accomplish this, numerous samples need to be analyzed to properly classify bacterial isolates as human or nonhuman. Methods such as Ribotyping (RT), Polymerase Chain Reaction (PCR), and Pulse-Field Gel Electrophoresis (PFGE) have demonstrated their capability to the task but tend to require expensive equipment, need skilled technicians, are time consuming, and have a high cost per sample. This investigation compares Biolog Phenotype MicroArrays^{TM} biochemical phenotype method to an established pulse-field gel electrophoresis molecular genotype method as a simple and low cost alternative for the discriminant analysis of *E. coli* in differentiating human and nonhuman sources of fecal pollution.

Regan, Genevieve*, **Ariel Royzin**, and **Kenneth Wm. Thomulka**, Department of Biological Sciences, University of the Sciences in Philadelphia, Philadelphia, PA 19104. *Comparison of a Bioluminescence Reduction Bioassay and Minimal Inhibitory Concentration in the Evaluation of Toxicity Agriculture Pest Control Products.* — Toxicity was evaluated for 18 commercially available pesticides, insecticides and herbicides, using Minimal Inhibitory Concentration (MIC) and a bioluminescence reduction bioassay in which bioluminescence reduction is proportional to toxicity. *Vibrio harveyi* and *Escherichia coli* containing a lux plasmid were used. The MIC and luminescence reduction concentrations were compared. The MIC for 7 products was determined and similar for both *V. harveyi* and *E. coli*. The MIC could not be determined for 11 products due to product turbidity. Luminescence reduction was determined by visual inspection. It could not be determined for 5 products, 8 products had equal toxicity for *Vibrio* and *E. coli*, Vibrio was more sensitive for 4 products, and *E. coli* was more sensitive for 1 product. Luminescence reduction was more sensitive than MIC. Presently luminescence reduction is being determined using a luminometer. Preliminary results for 6 products indicate that luminescence reduction is more sensitive than MIC. These results suggest that the 1 hour bioluminescence reduction bioassay is a faster and more sensitive method than the traditional MIC method of determining the microbial sensitivity.

† The abstracts published herein have not been subjected to editorial scrutiny.
* Authors presenting the paper.

PENNSYLVANIA ACADEMY OF SCIENCE JOURNAL INFORMATION FOR AUTHORS

EDITORIAL POLICY AND FORMAT

The *Journal* of the Pennsylvania Academy of Science publishes original papers, research notes, commentary, and review articles in the natural, physical, engineering, and social sciences. All papers must discuss the relevance of the data presented and a clear interpretation of its meaning in view of current knowledge of the discipline concerned. Helpful references for the author are: (1) Day, R.A. 1983. How to write a scientific paper. 2nd ed. ISI Press, Philadelphia, xv + 181 pp.; (2) O'Connor, M. and F.P. Woodford. 1976. Writing scientific papers in English, Elsevier, Amsterdam, vii + 108 pp.; (3) MacGregor, A.J. 1979. Graphics simplified; and (4) How to plan and prepare effective charts, graphs, illustrations, and other visual aids, University of Toronto Press, Toronto, 1–64 pp.

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2. *Headings.* All headings are in CAPITAL letters and centered.

3. *Title.* Brief and to the point. It should inform the reader of the subject of the paper.

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8. *Results and Discussion.* The Results section is a clear and concise account of the findings. Data should be presented in the most efficient manner, either in text, tables, or illustrations. All tables and illustrations must be referenced in the text. The Discussion section should extend or contradict current published information on the subject. Limit the discussion to the relevant subject and avoid speculation.

9. *Acknowledgments.* These should be as brief as possible.

10. *Literature Cited and Footnotes.* Except for title and author reference at the beginning of the paper, and superscript notation in tables, do not use footnotes. Create separate Appendices or an Endnotes section if additional supplementary text material is required. Place Endnotes section just before the Literature Cited section. Number each endnote within the Endnote section using Arabic numbers in the order in which they are referred to in the other sections of the manuscript. In other sections of the manuscript, place endnotes reference numbers in parentheses, and use the text style of type and not superscript. Place appendices after the Literature Cited section: Include a Literature Cited section: list references in alphabetical order by first author. Include only published references cited in the manuscript; unpublished work normally will be cited as personal communication (pers. comm.) in other sections of the manuscript, e.g., J.R. Halma (pers. comm.) or (J.R. Halma, pers. comm.). List all authors and full citation in the Literature Cited section. Use the most recent issue of the recognized abstracting authority to determine the correct abbreviations of periodical names (e.g., for biology use BIOSIS, Bioscience Information Service, Philadelphia, PA). If in doubt do not abbreviate serial names. Use the following format and style for the Literature Cited section: Journal–Monmonier, M. 1987. Title. J. Pa Acad. Sci. 62:73–77.

Book (Select pages)–Snedecor, G.W. and W.G. Cochran. 1976. Statistical Methods. The Iowa State University Press. Ames, IA, 237–238.

Book (Complete work)–Snedecor, G.W. and W.G. Cochran. 1976. Statistical Methods. The Iowa State University Press. Ames, IA, xix + 593 pp.

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